

# An Improved Josephson Junction Based Quantum Bit

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**Post Docs**

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Research**

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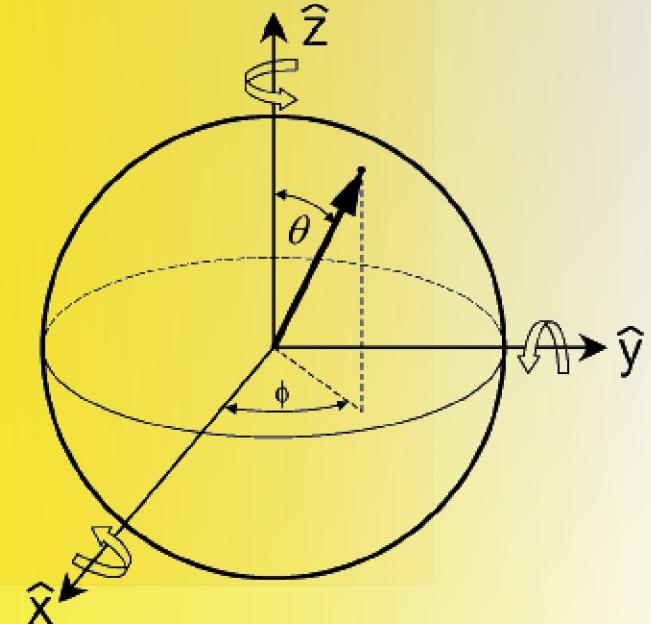
**Principal Investigator**



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Technology Administration, U.S. Department of Commerce

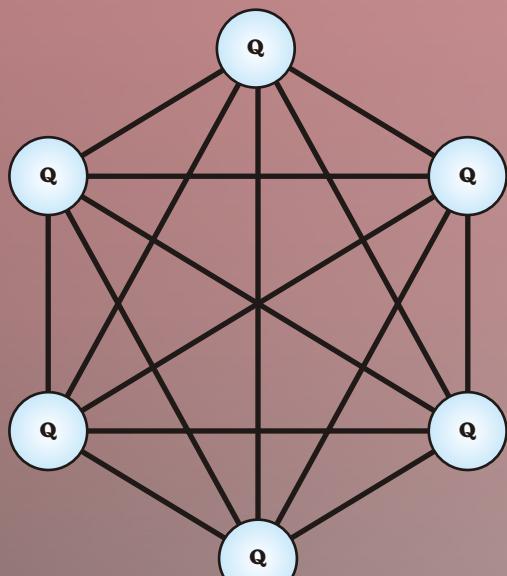
# Quantum Computers: Is it just fantasy?

- **What systems can be used as Quantum Bits?**
- **How do we control them?**
- **How do we measure them?**
- **How do we couple them?**
- **Are they reliable enough?**
- **Is it all worth it?**

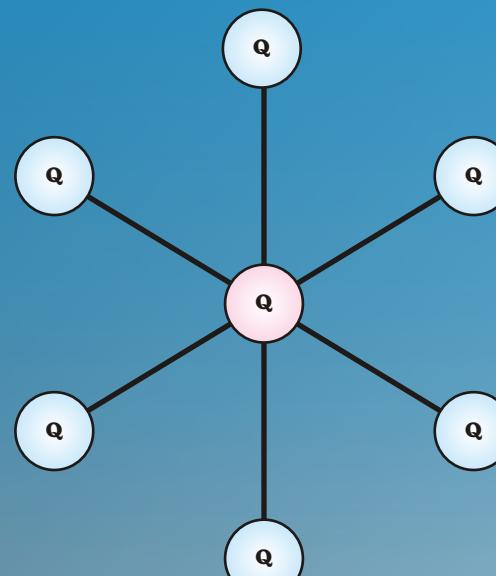


# Two Possible Architectures For Quantum Computing

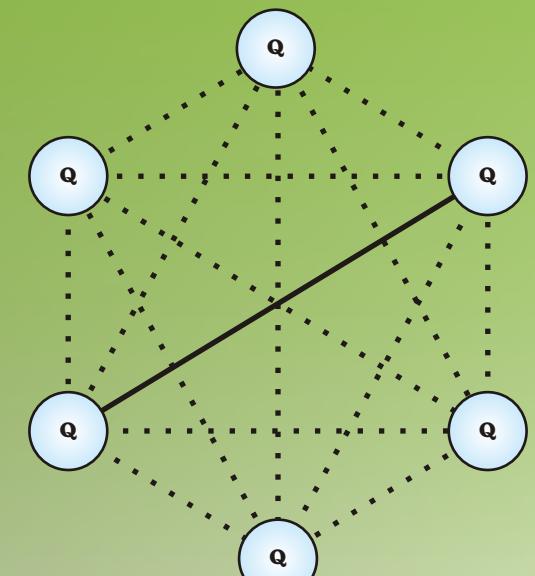
**“Nodal”**

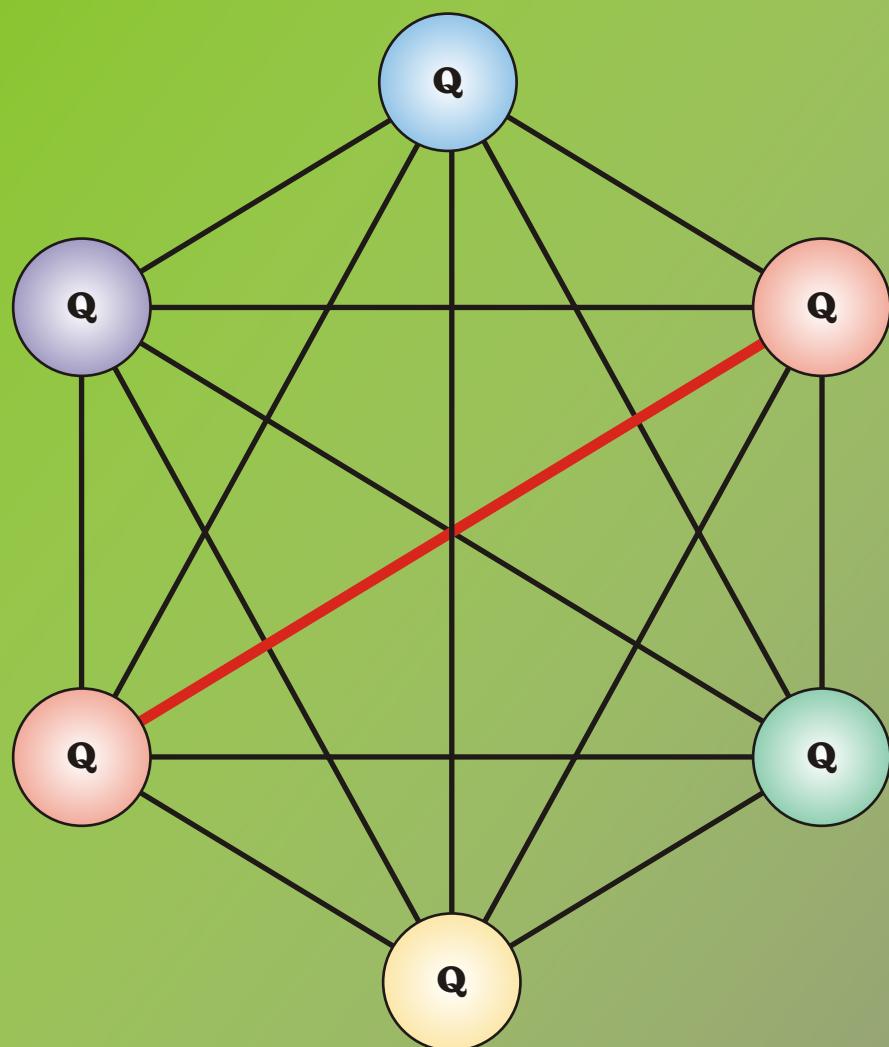


**“Mediated”**



**“Variable”**



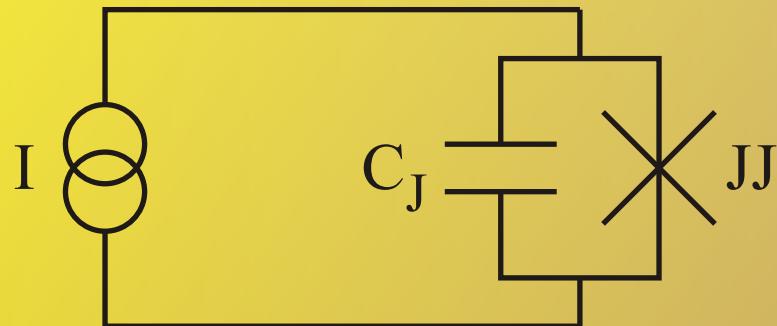


## For Solid State Systems:

- ✓ **nodal scheme**
- ✓ **tune qubits for resonant coupling**
- ✓ **use micro-fabrication technology**
- ✓ **scale to > 100 qubits**



# The Current Biased Josephon Qubit

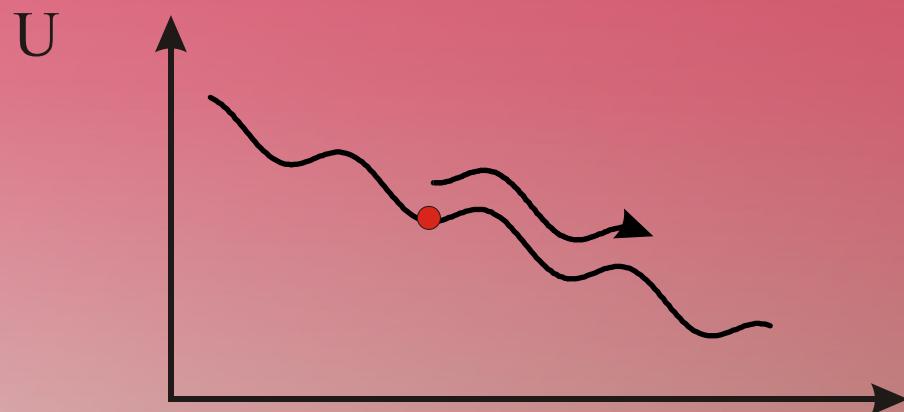


The Josephson Relations

$$I = I_0 \sin \frac{\hbar}{e} V$$

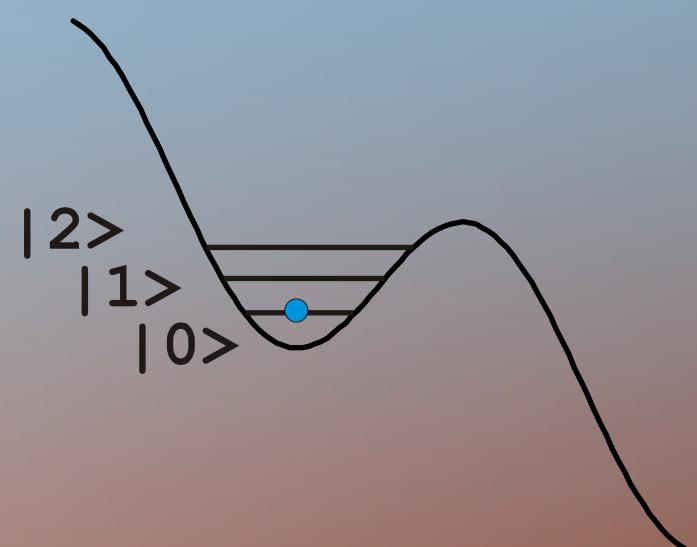
## Classical Behavior

$$U = \frac{I_o}{2} \cos \frac{I}{I_o}$$

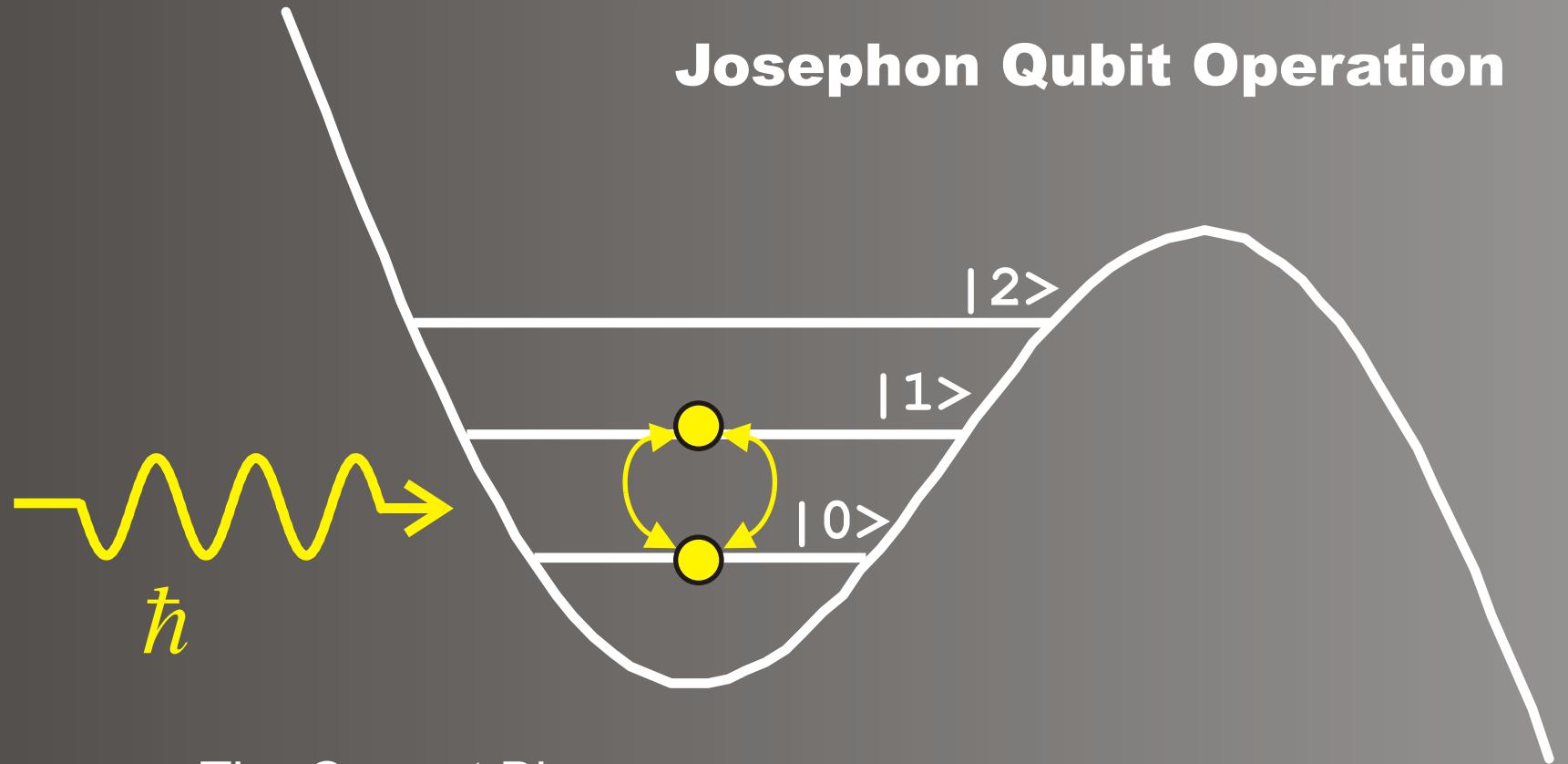


## Quantum Behavior

$$H = \frac{C_J}{\hbar} \hat{q}^2 + \frac{I_o}{2} \cos \hat{q} + \frac{I_o}{2} \hat{q}^2$$



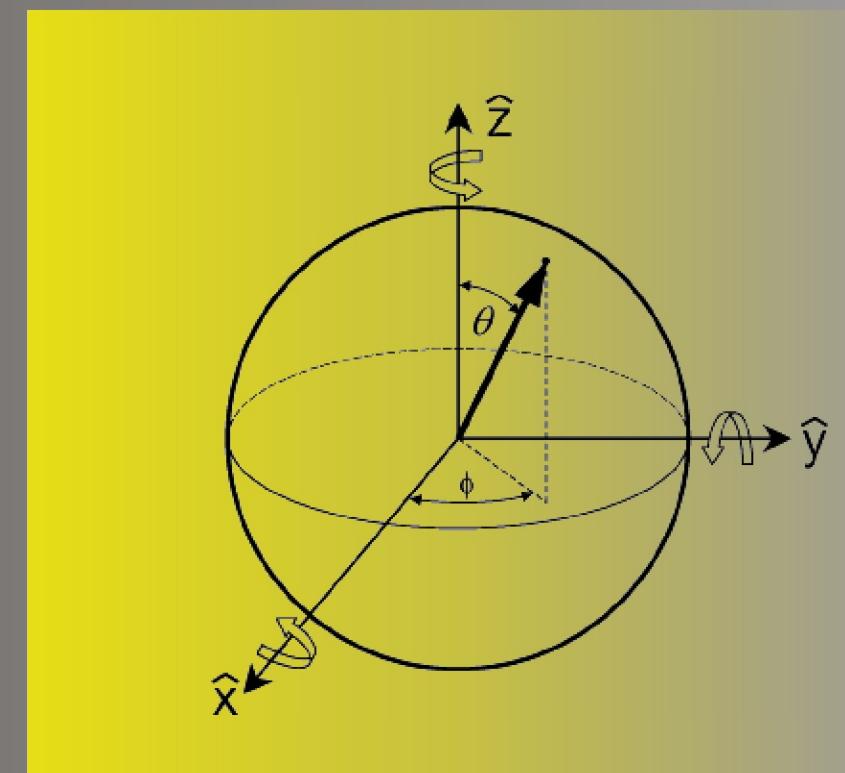
# Josephon Qubit Operation



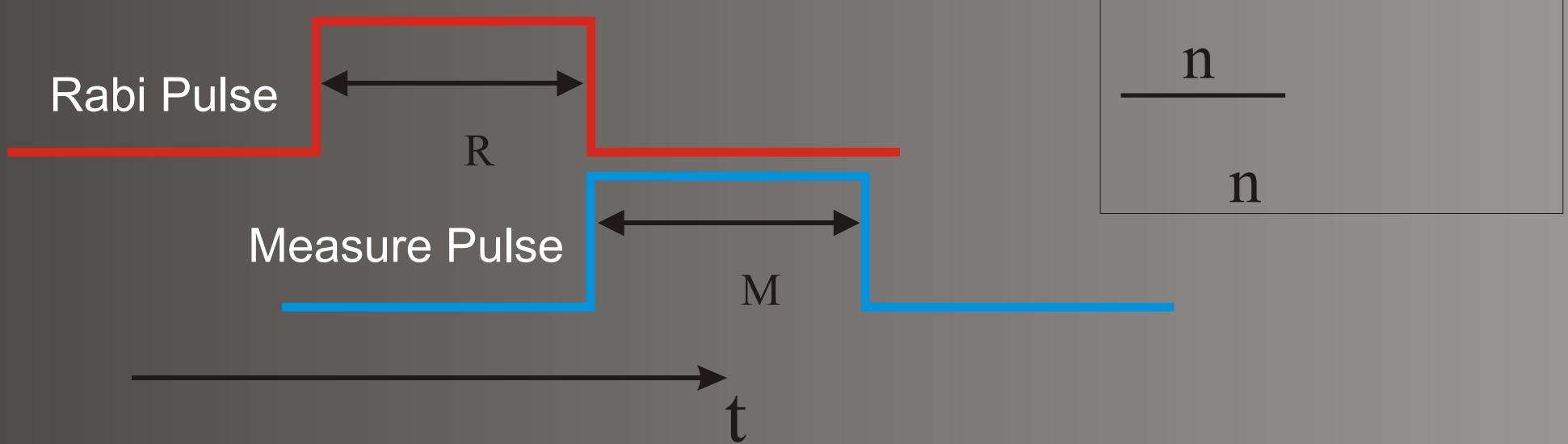
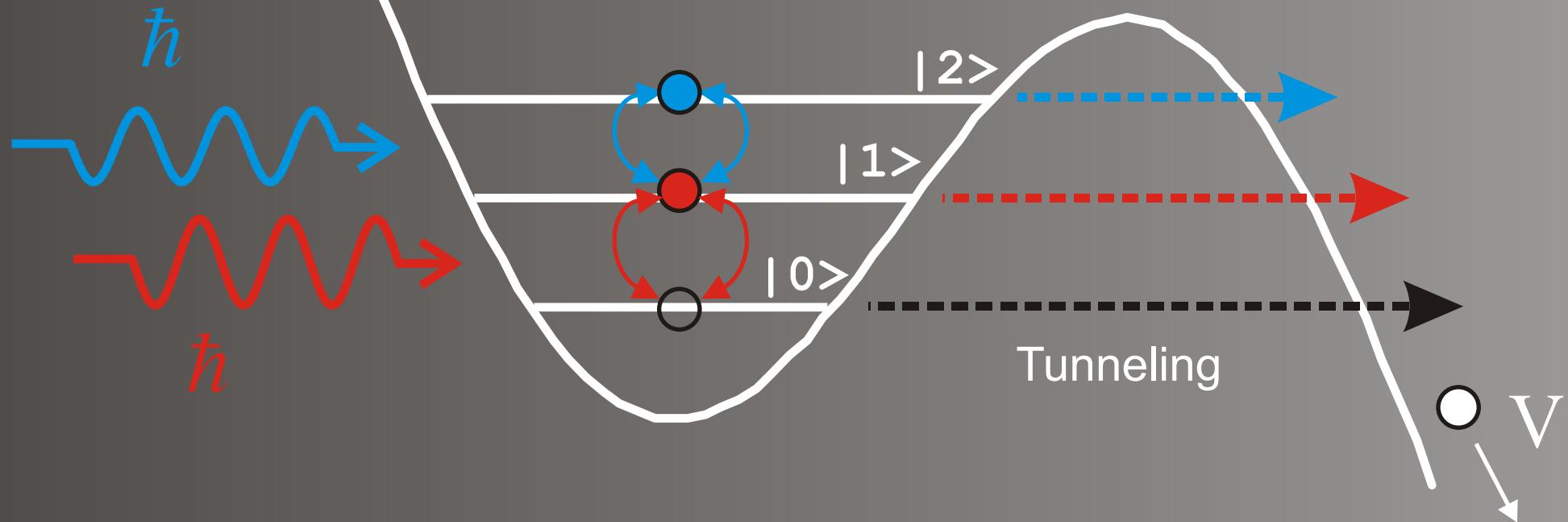
The Current Bias

$I t \quad I \quad I t \quad I_c \cos \quad t \quad I_s \sin \quad t$

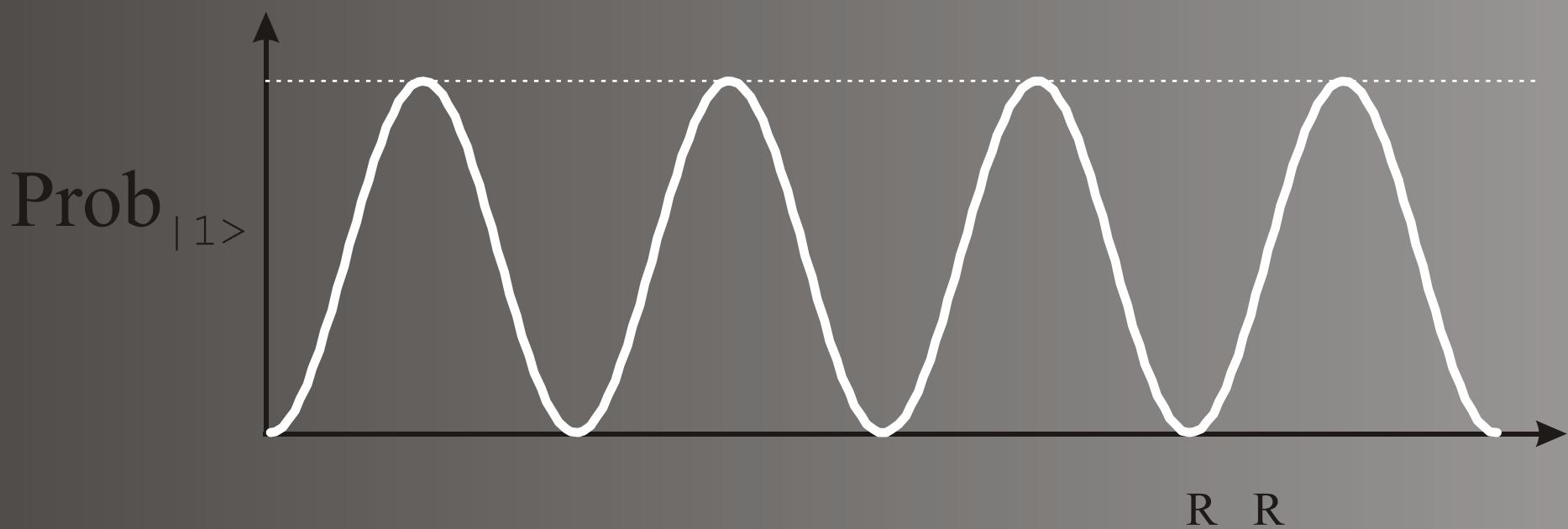
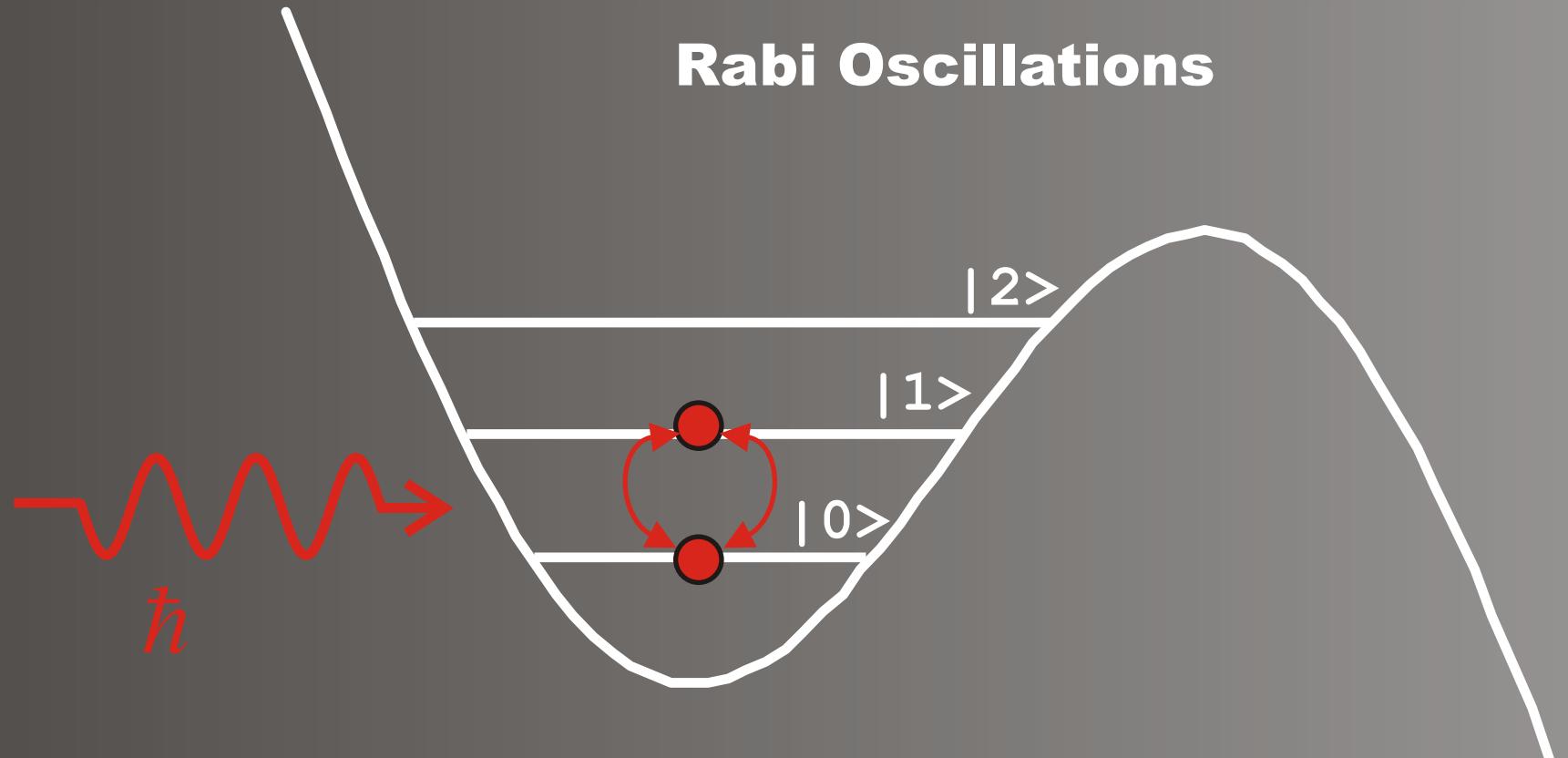
x	$I_c \cos$	$t$
y	$I_s \sin$	$t$
z	$I t$	



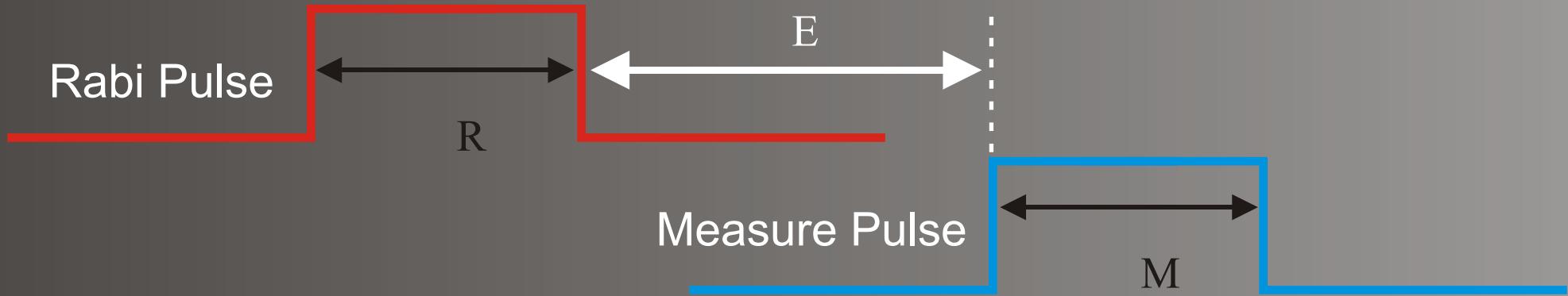
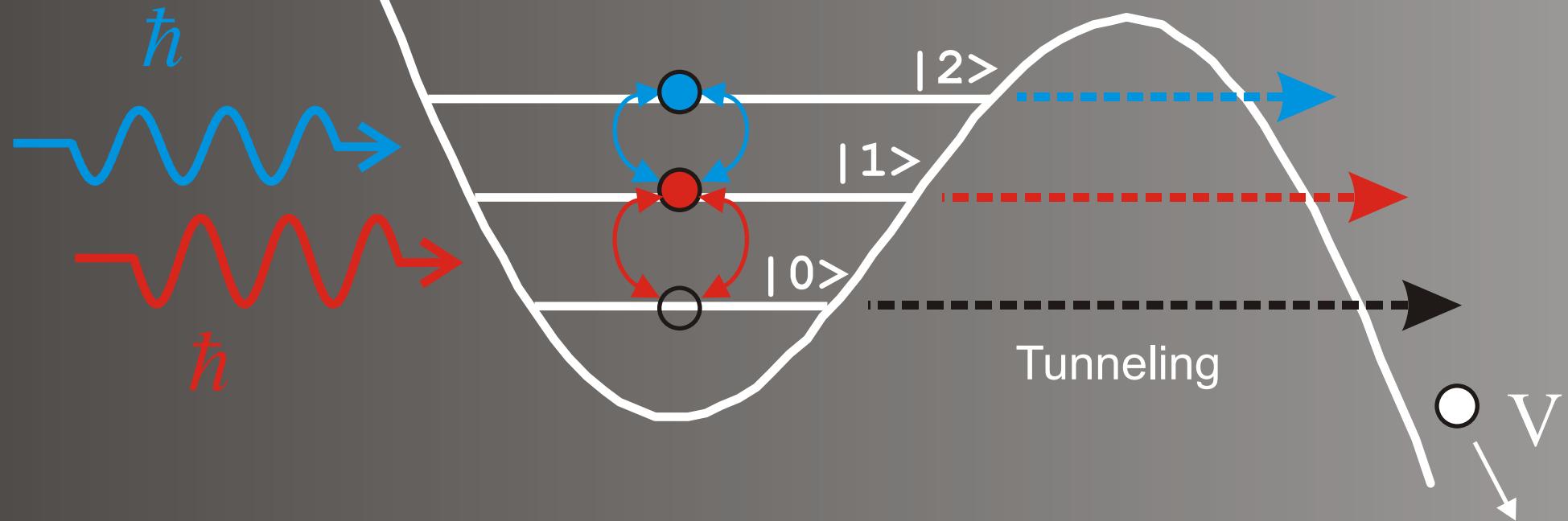
# State Measurement

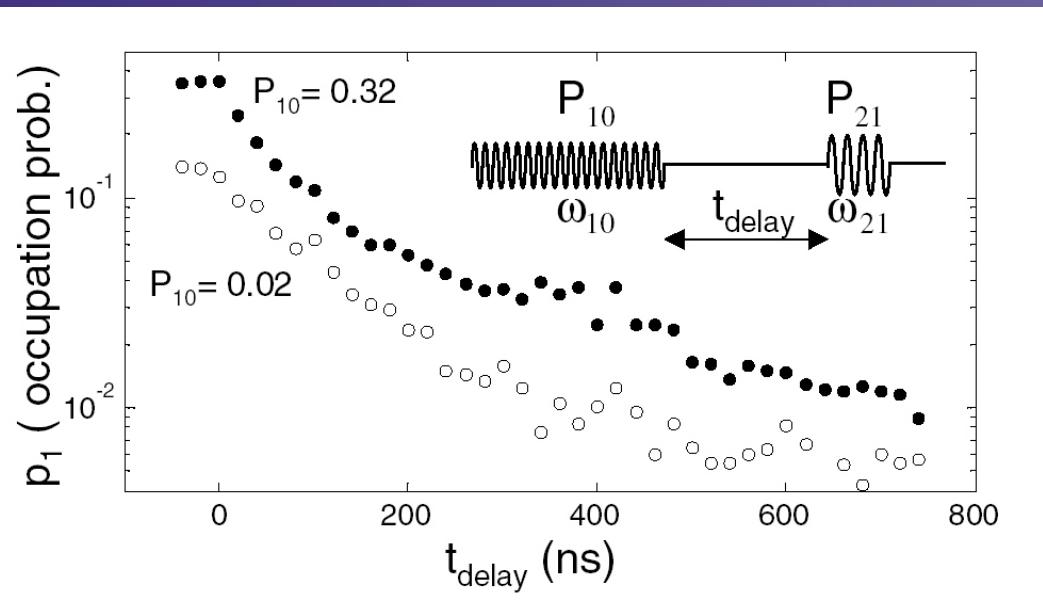


# Rabi Oscillations



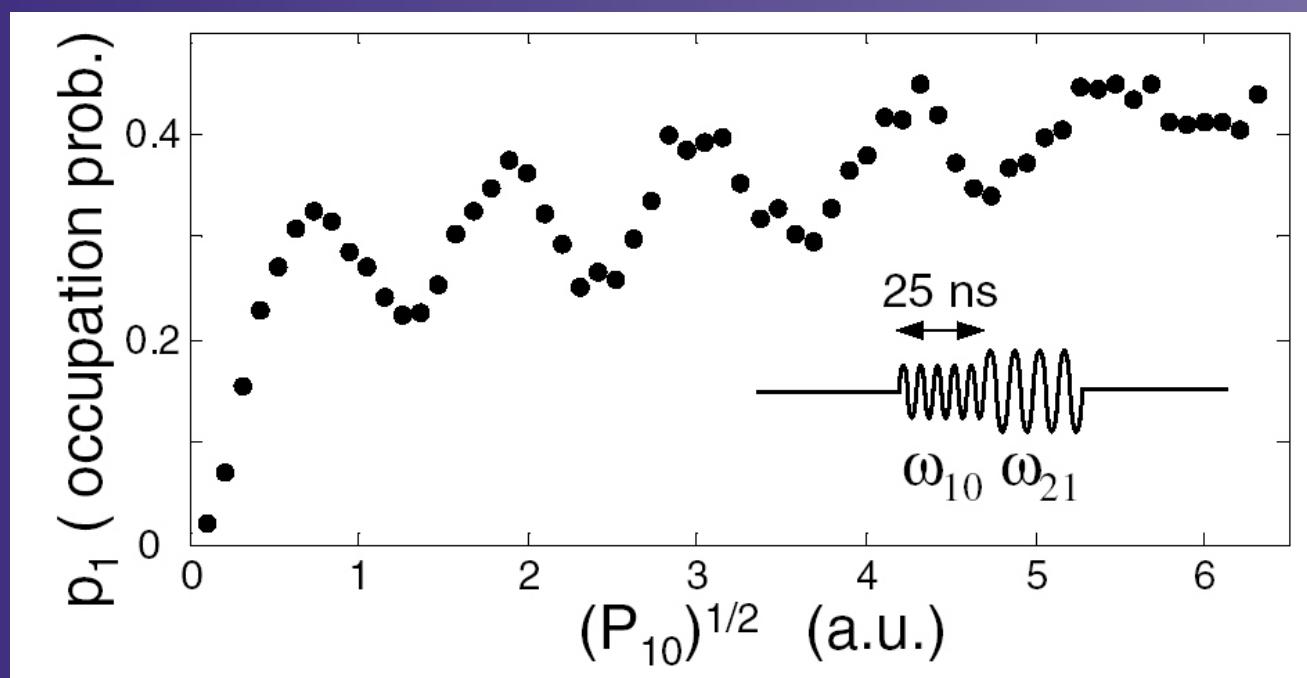
# Energy Relaxation Time





**Energy Relaxation Time**

$S$



**Rabi Oscillations**

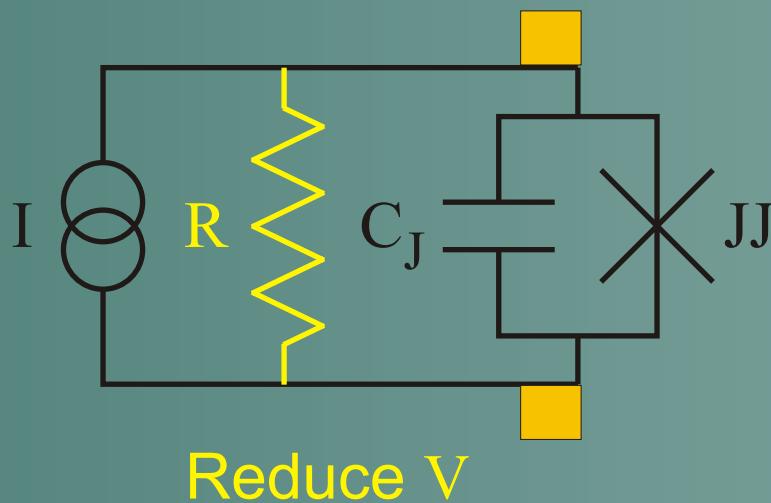
ns

# Problems with this design

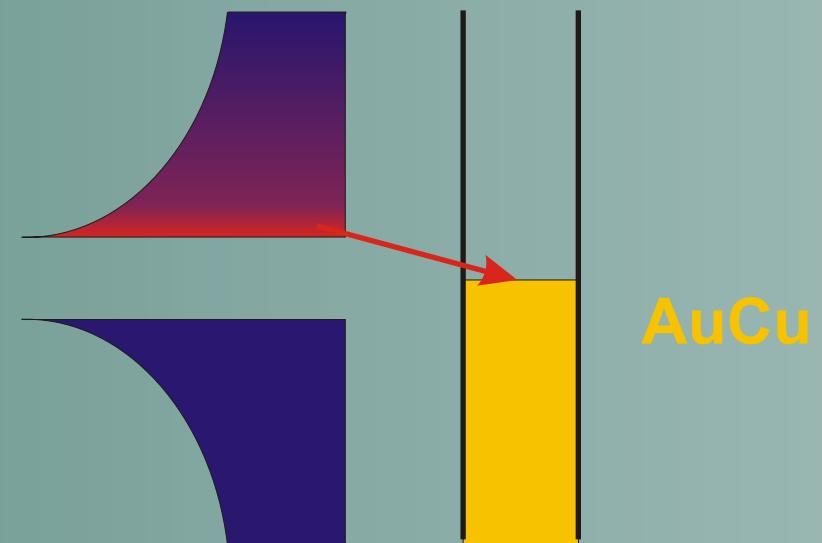
- Measurement too harsh!
- Quasiparticle heating.
- Need further isolation from environment.

Some improvements...

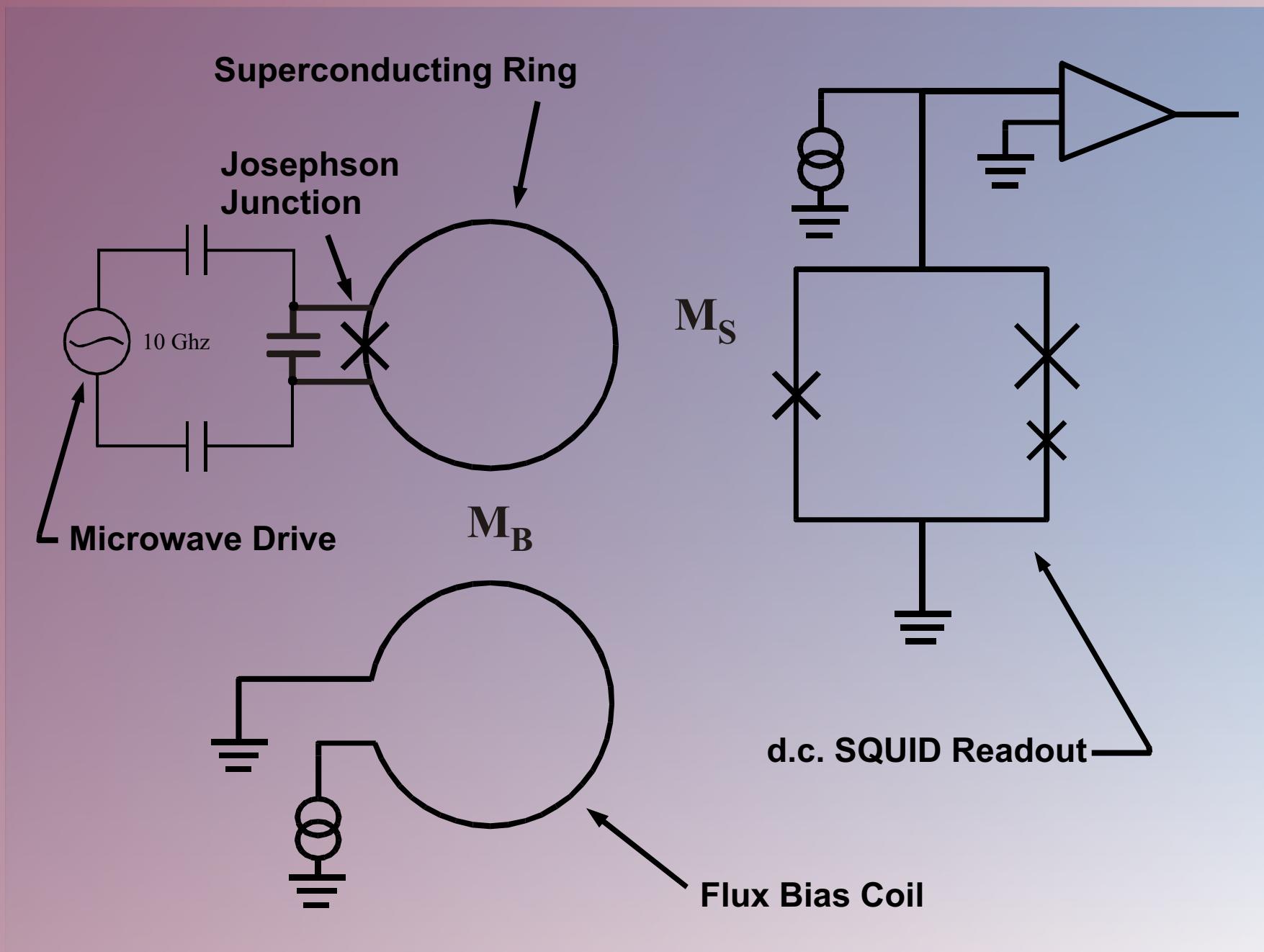
Resistive Shunt



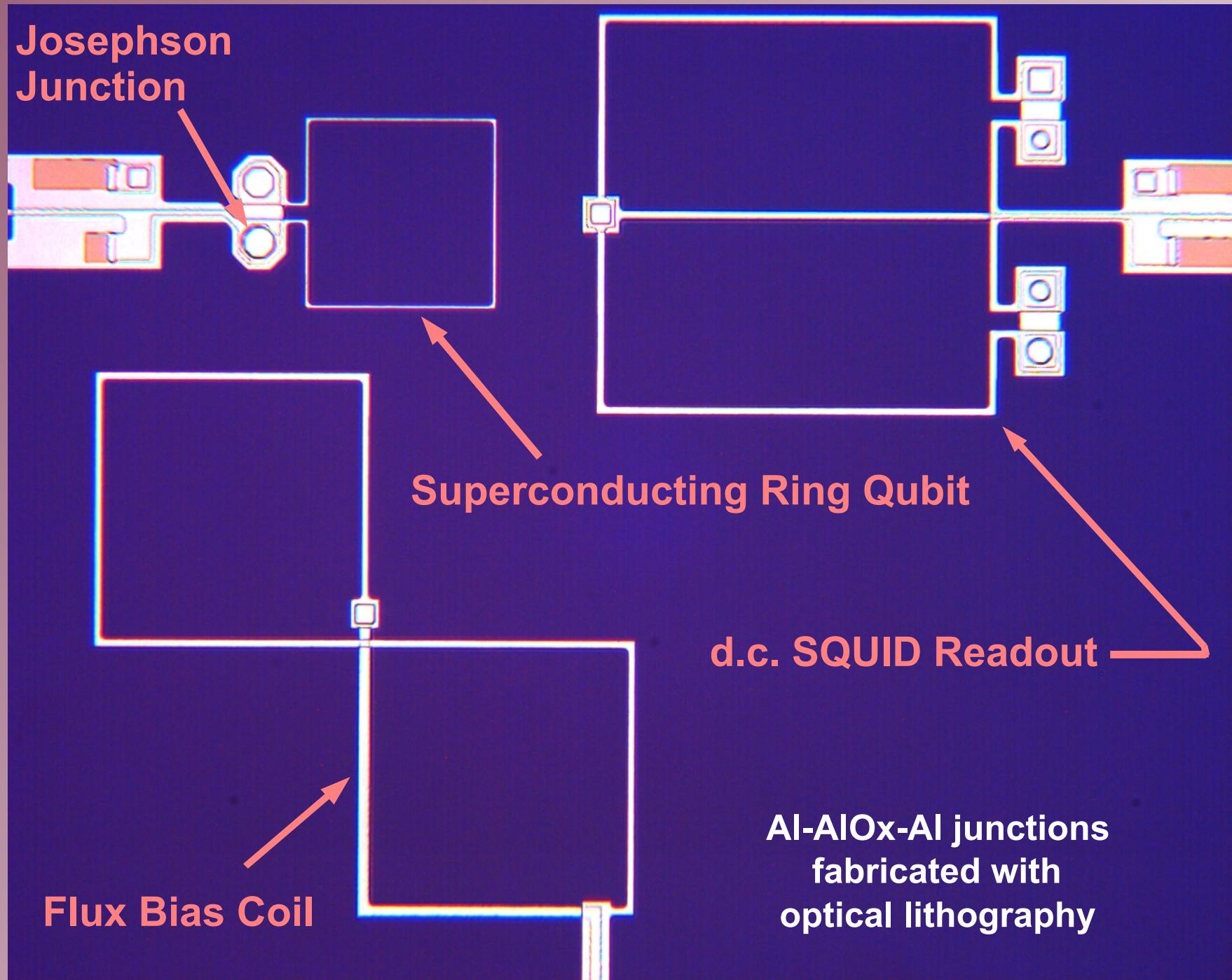
Quasiparticle Traps



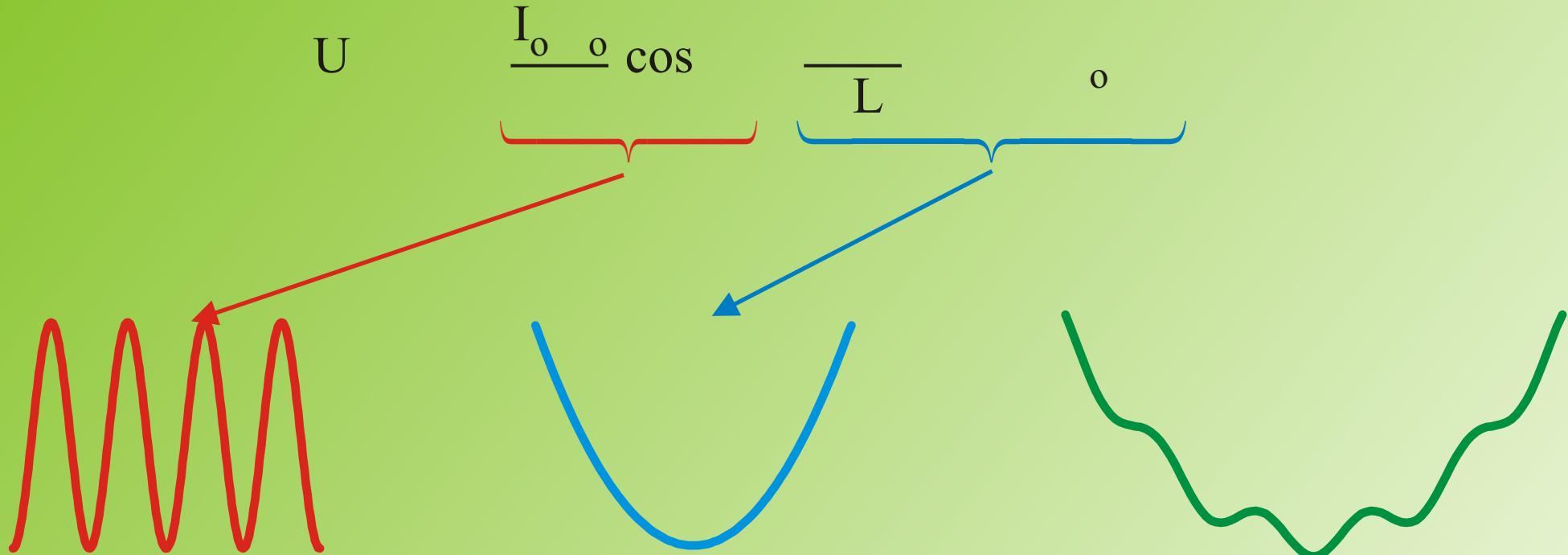
# A New Improved Josephson Qubit



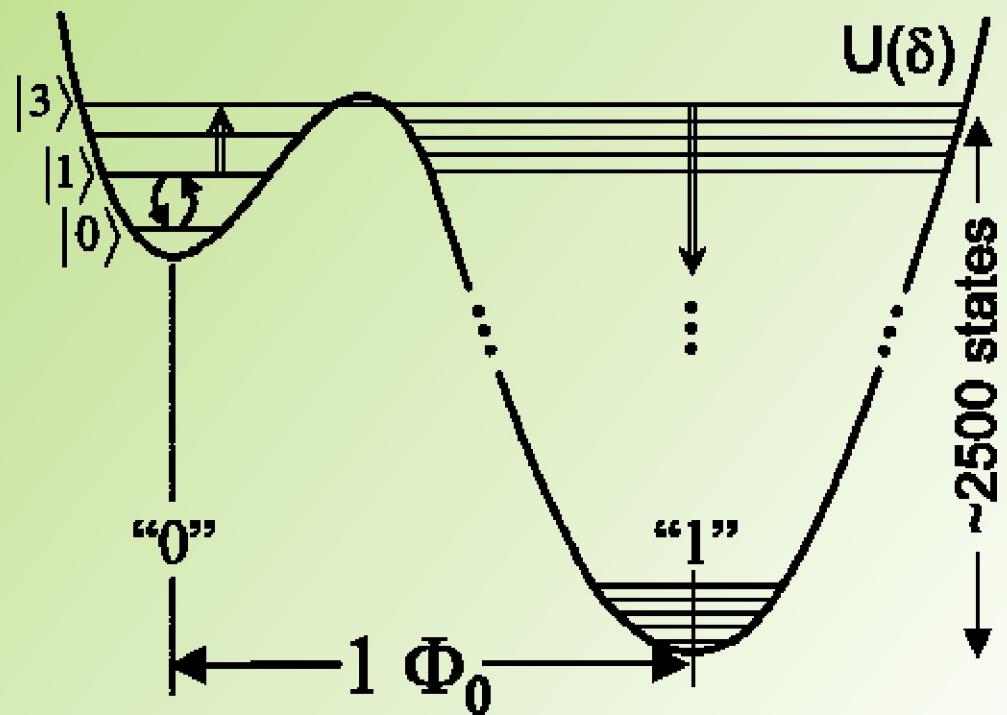
# A New Improved Josephson Qubit



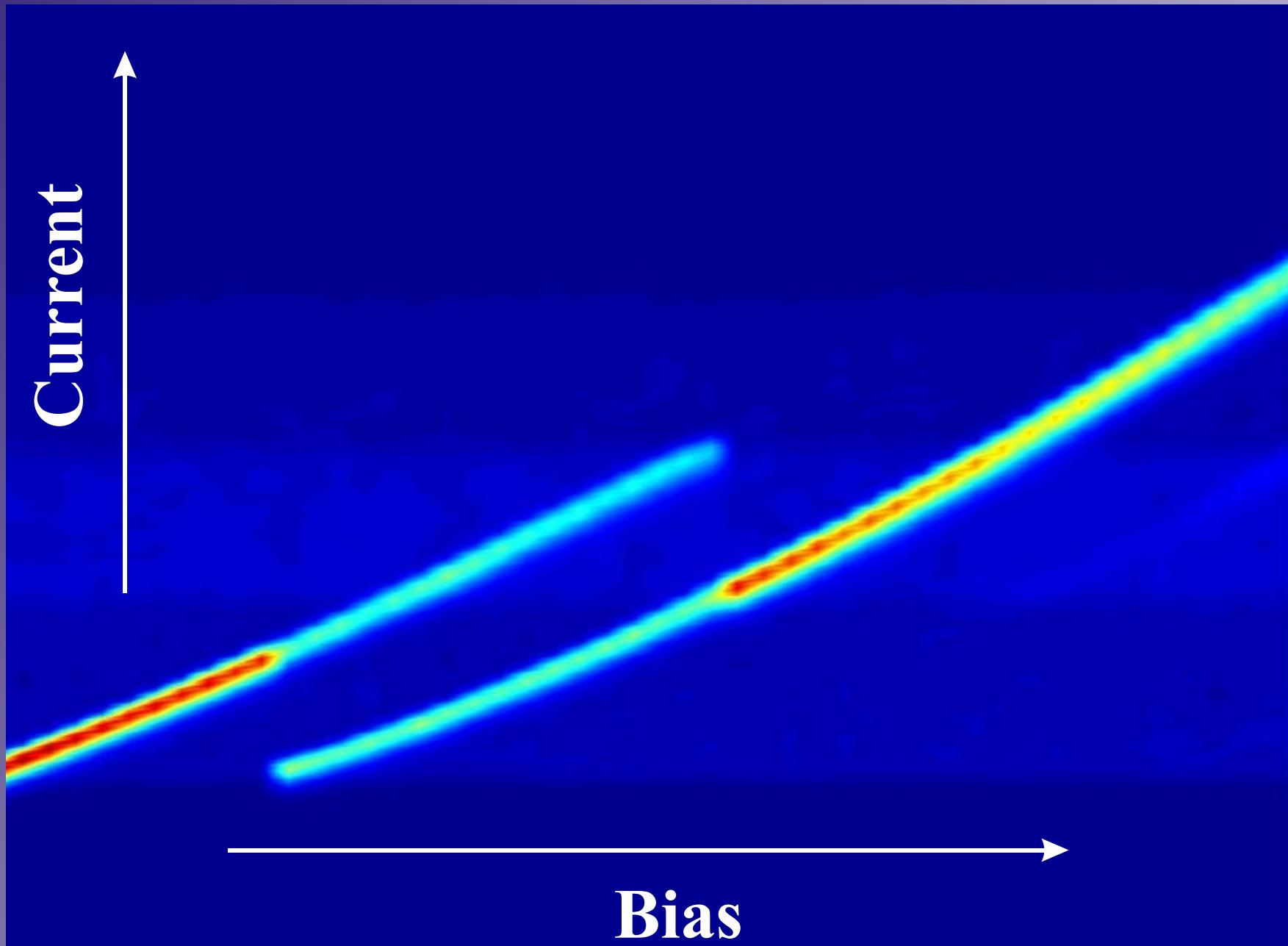
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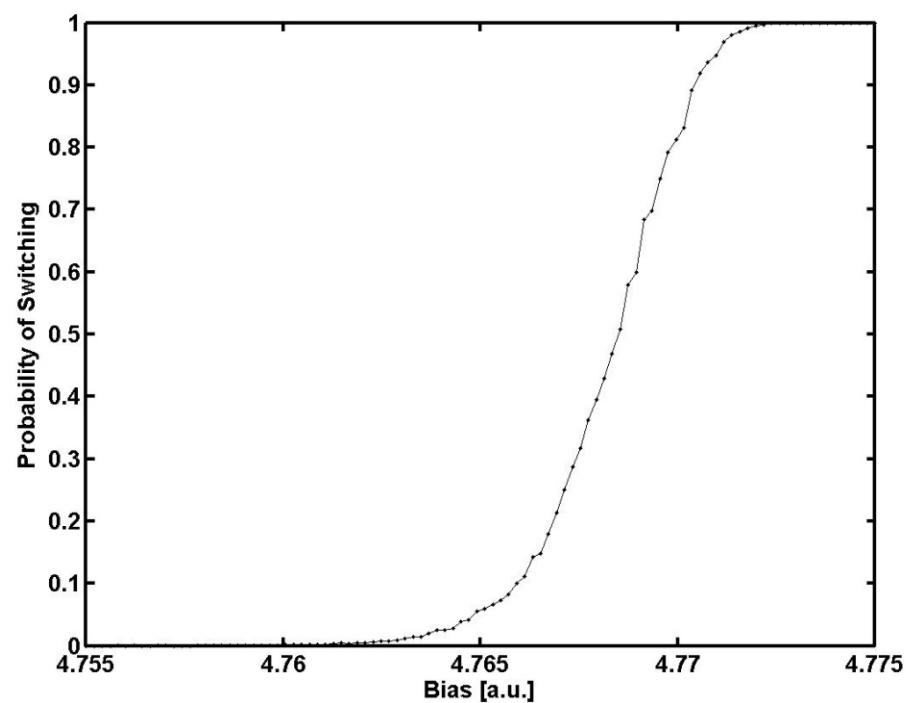
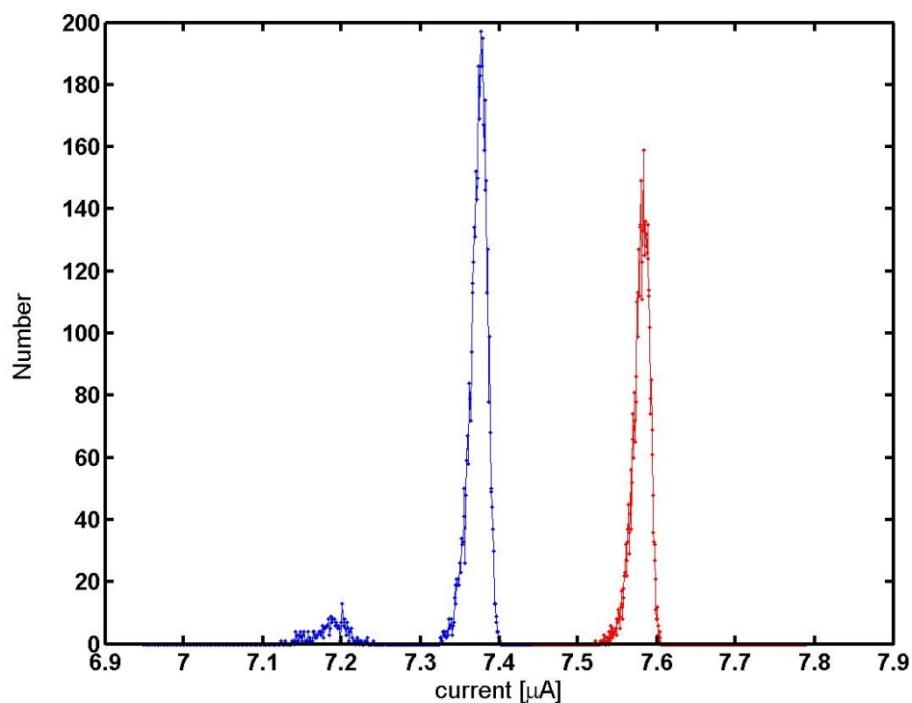
**Here is an example...**



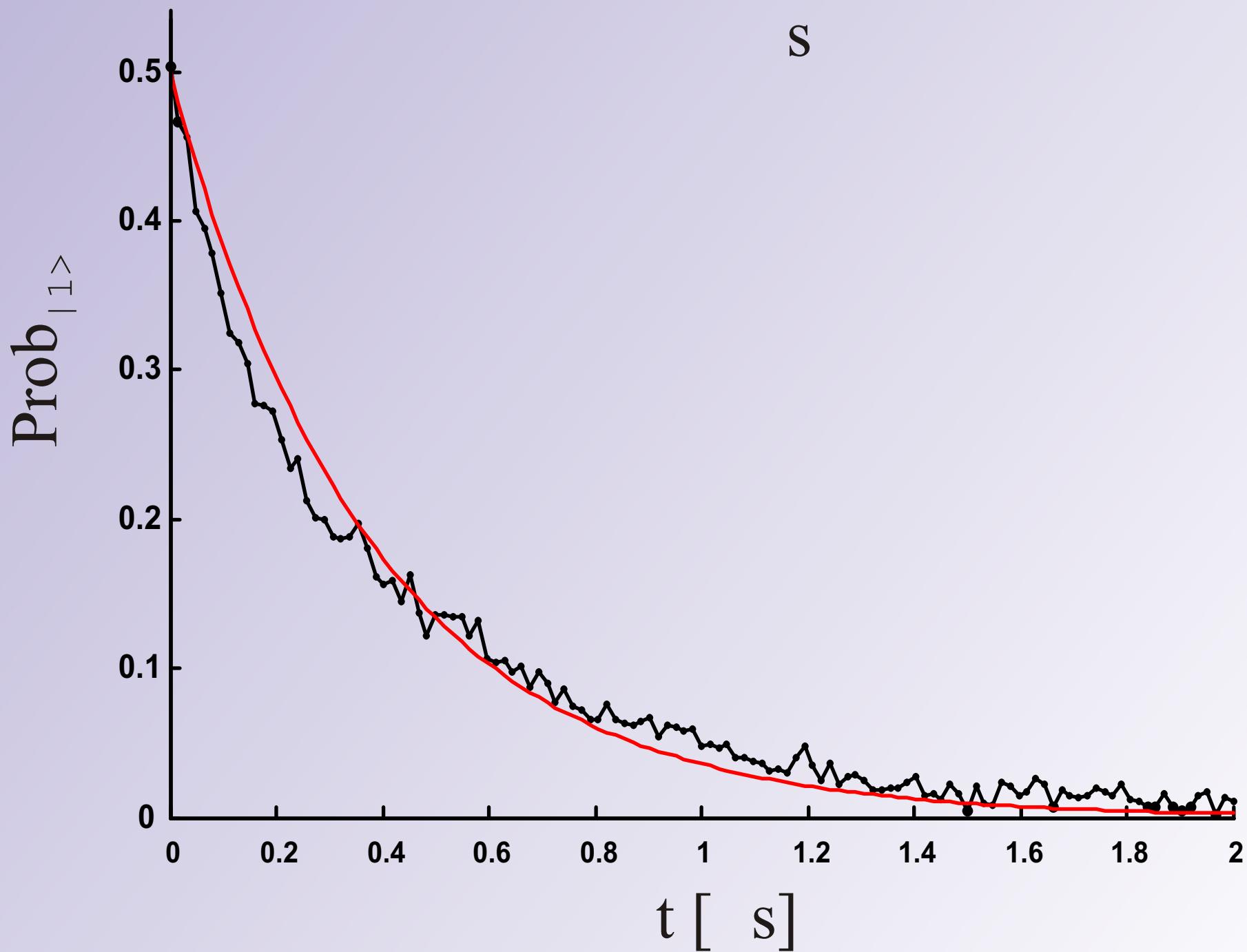
## Examples of the steps



## Examples of the step edge statistics

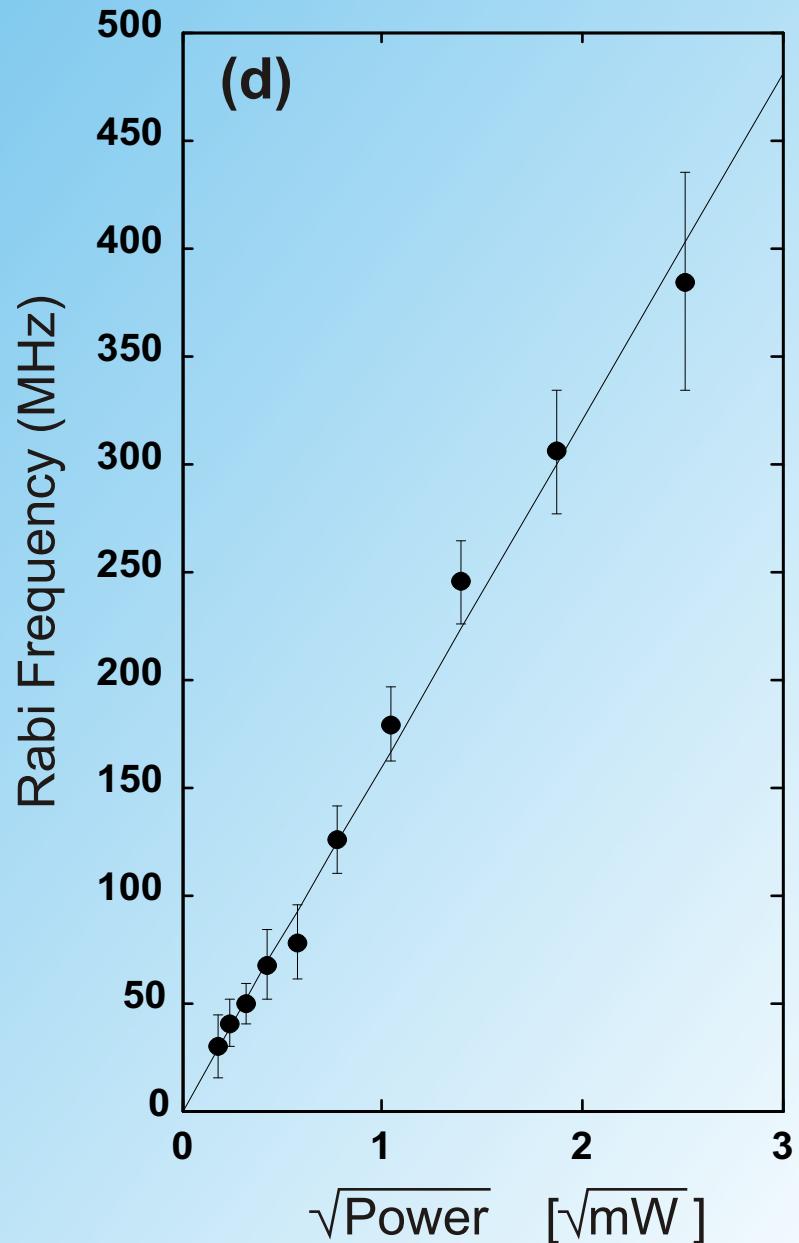
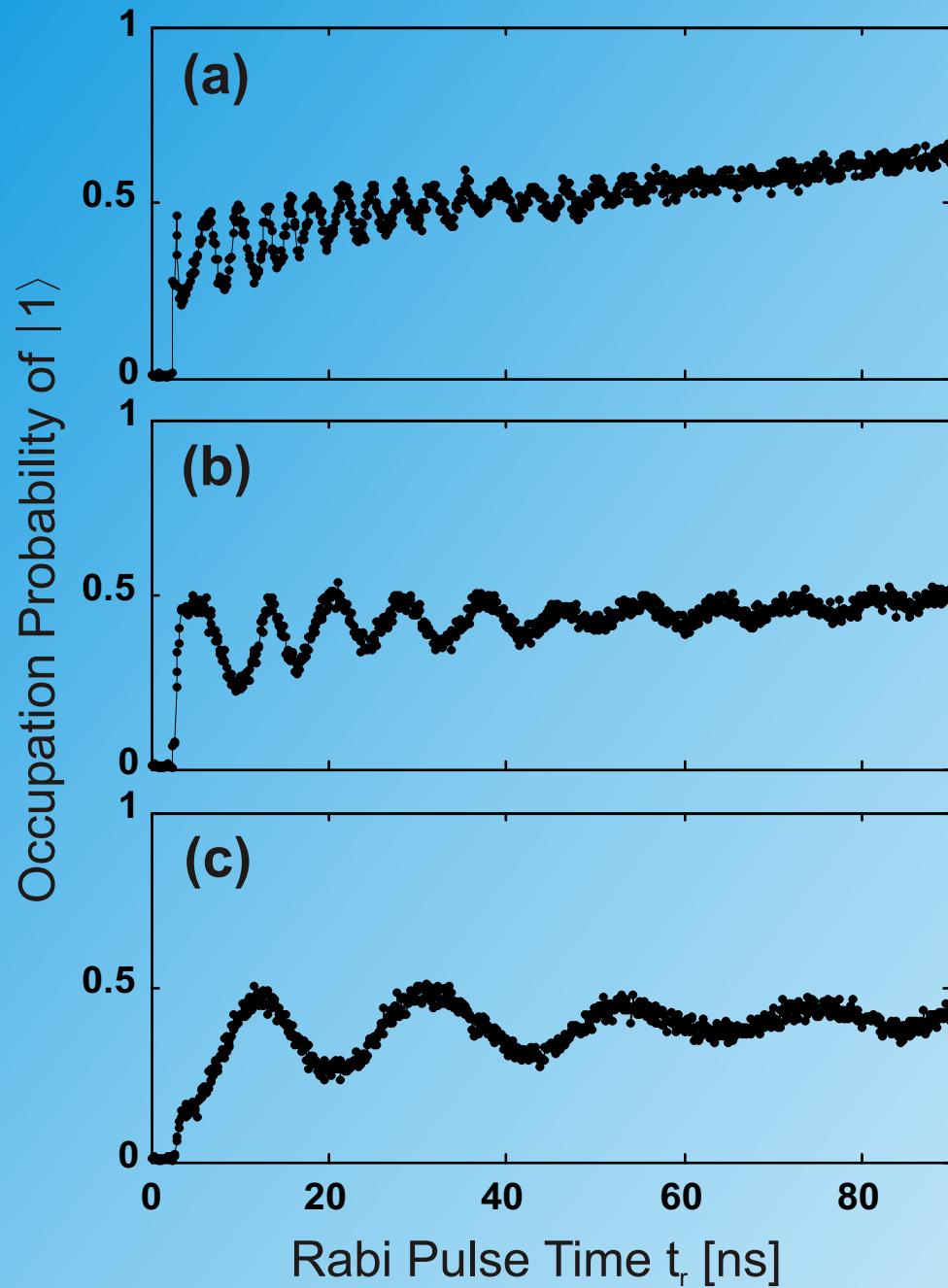


# Improved Energy Relation Time

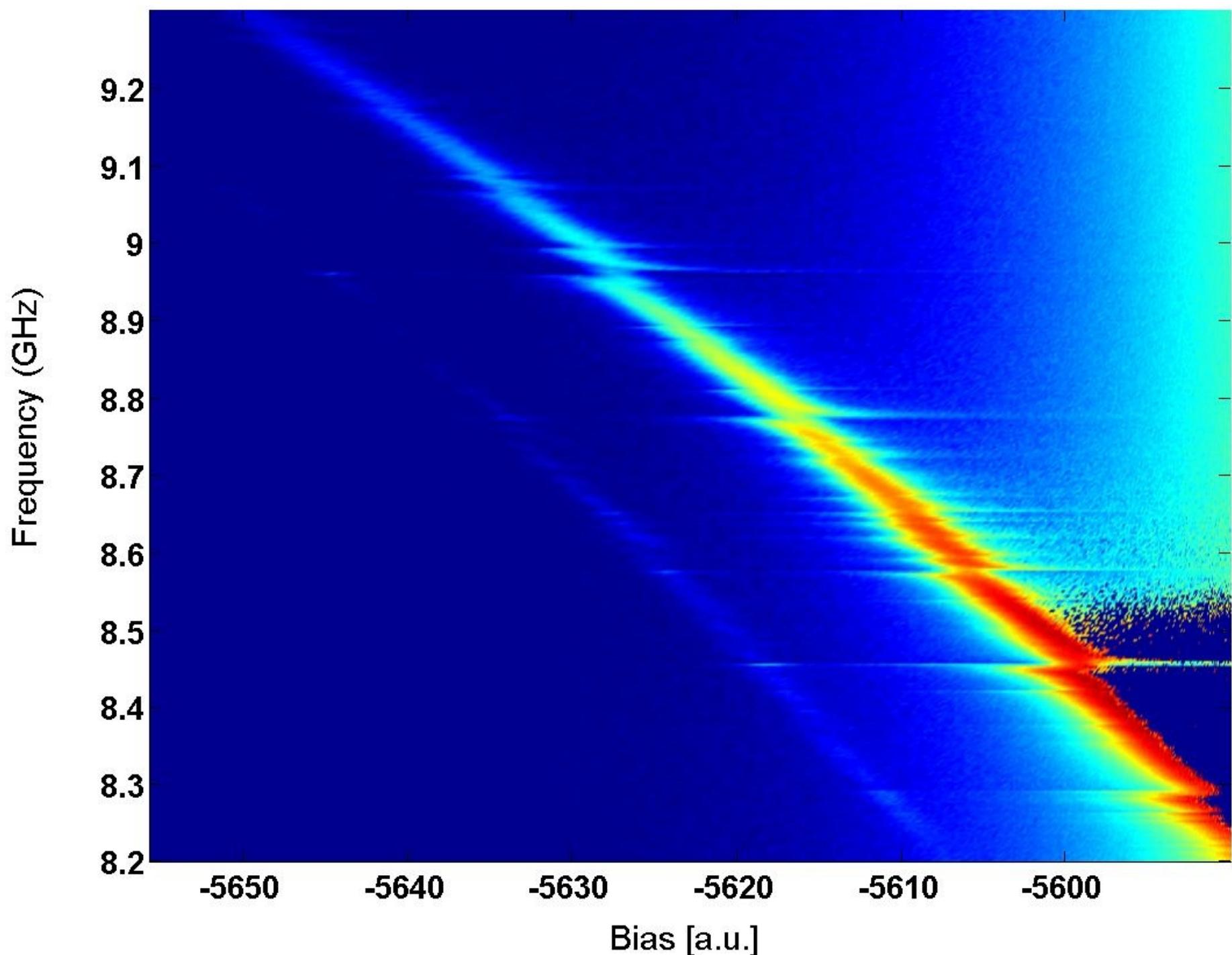


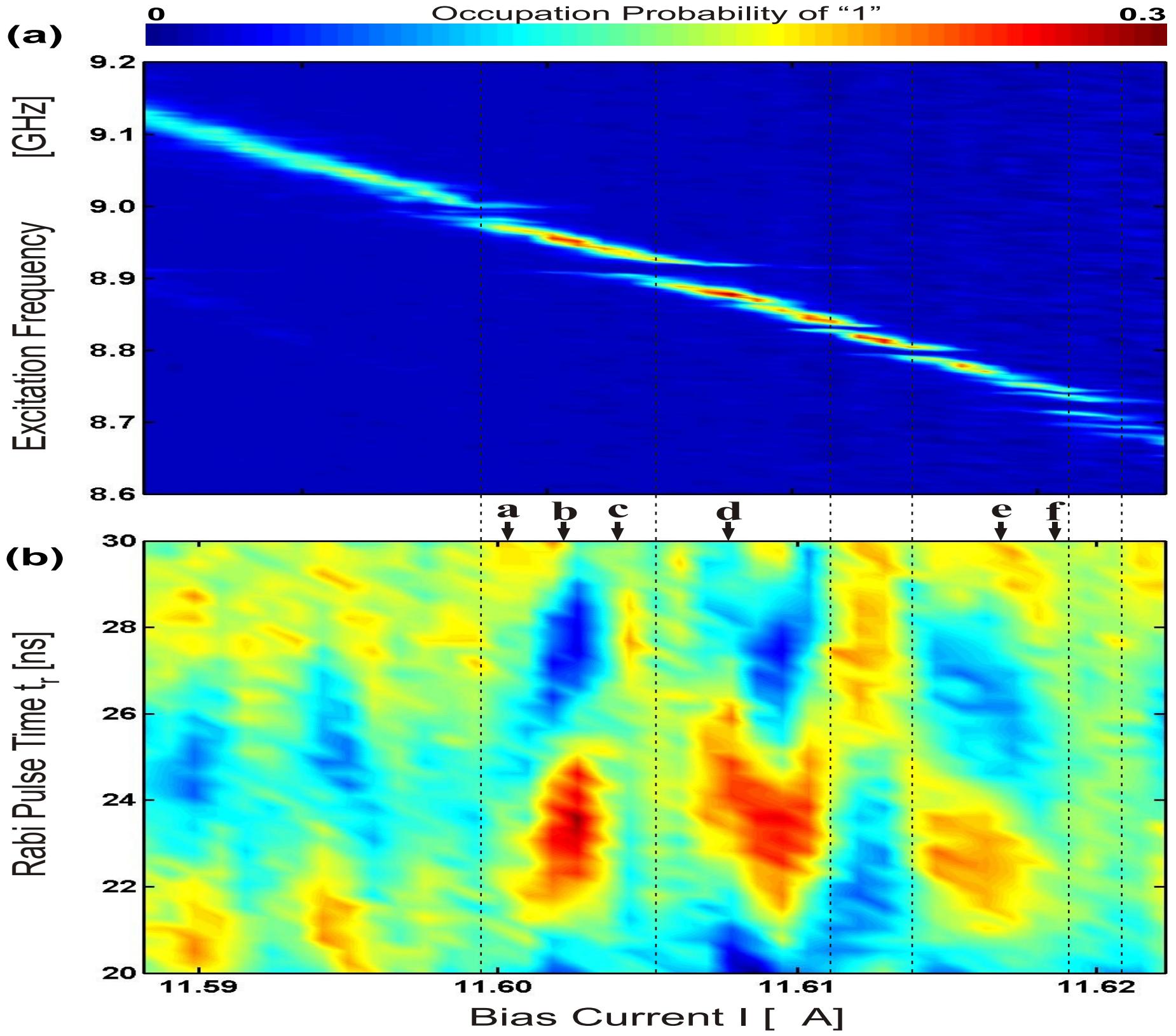
# Improved Rabi Oscillations

ns

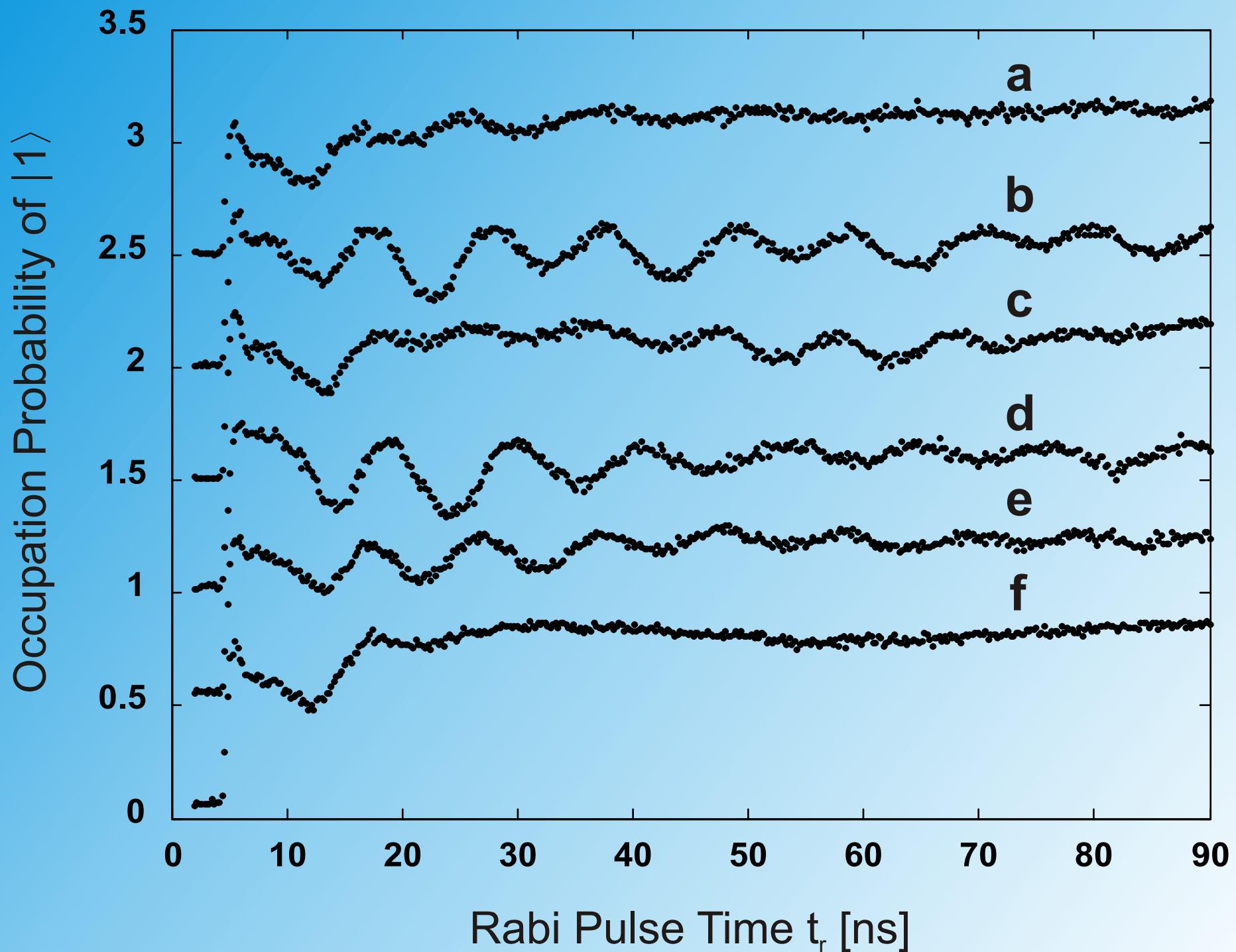


# Spectroscopy of the $|0\rangle \rightarrow |1\rangle$ transition

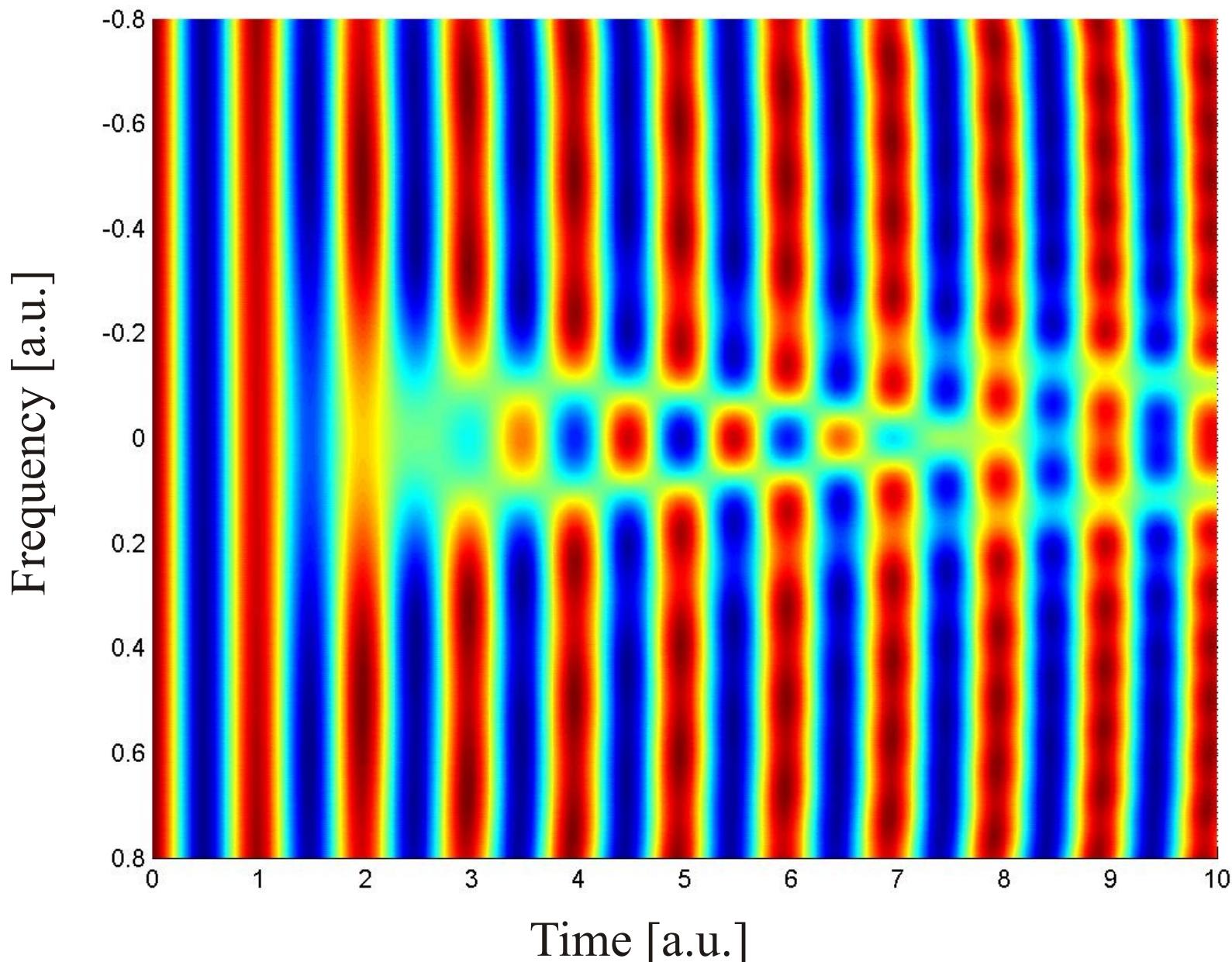




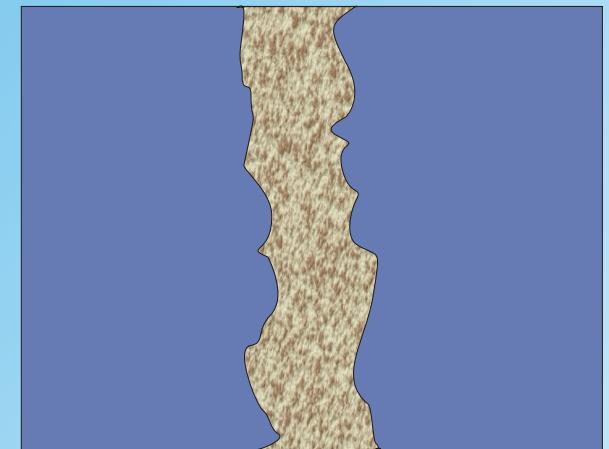
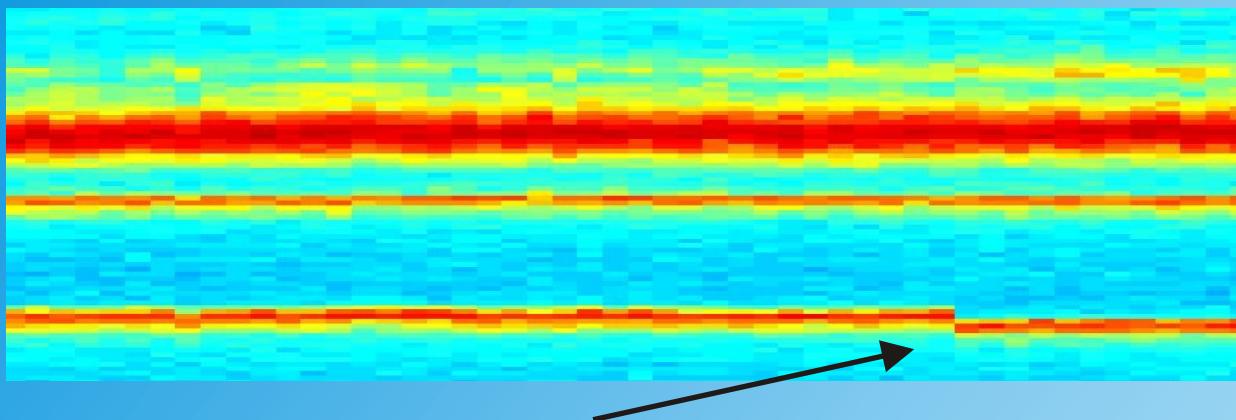
# Beating Of Rabi Oscillations



# **Simulations Of Rabi Oscillations**

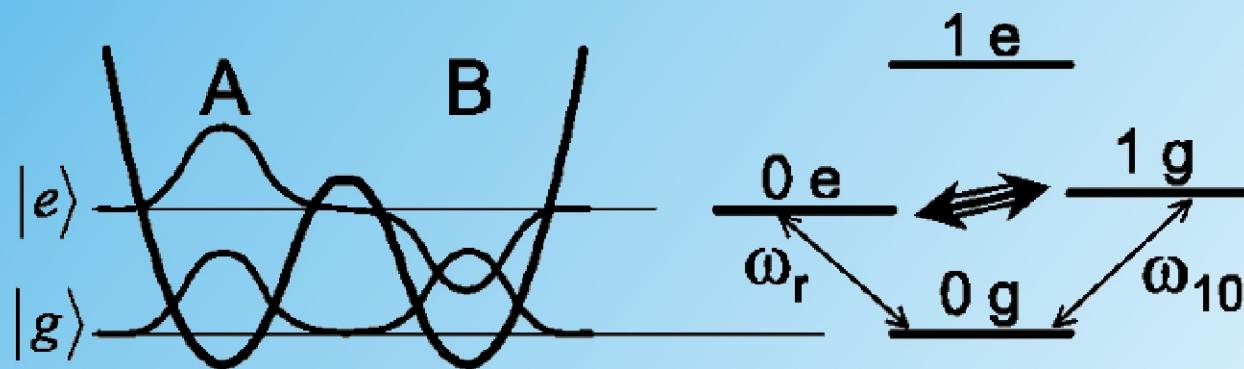


# Microscopic Two Level Fluctuators in the Tunnel Barriers



**Shift in time of resonance!**

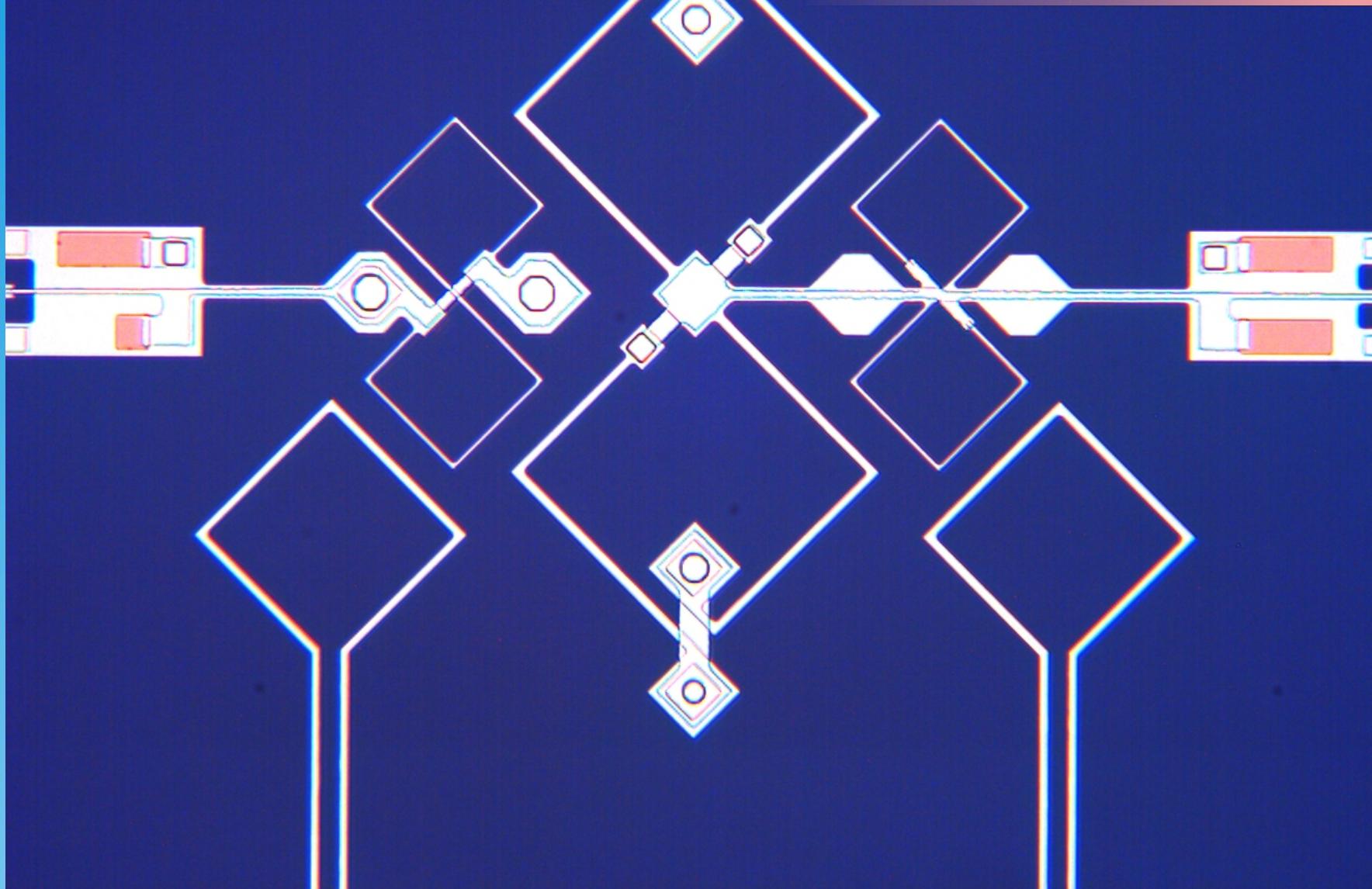
$$H_{int} = -\frac{I_{0A}\Phi_0}{2\pi} \cos \hat{\delta} \otimes |\Psi_A\rangle \langle \Psi_A| - \frac{I_{0B}\Phi_0}{2\pi} \cos \hat{\delta} \otimes |\Psi_B\rangle \langle \Psi_B|$$



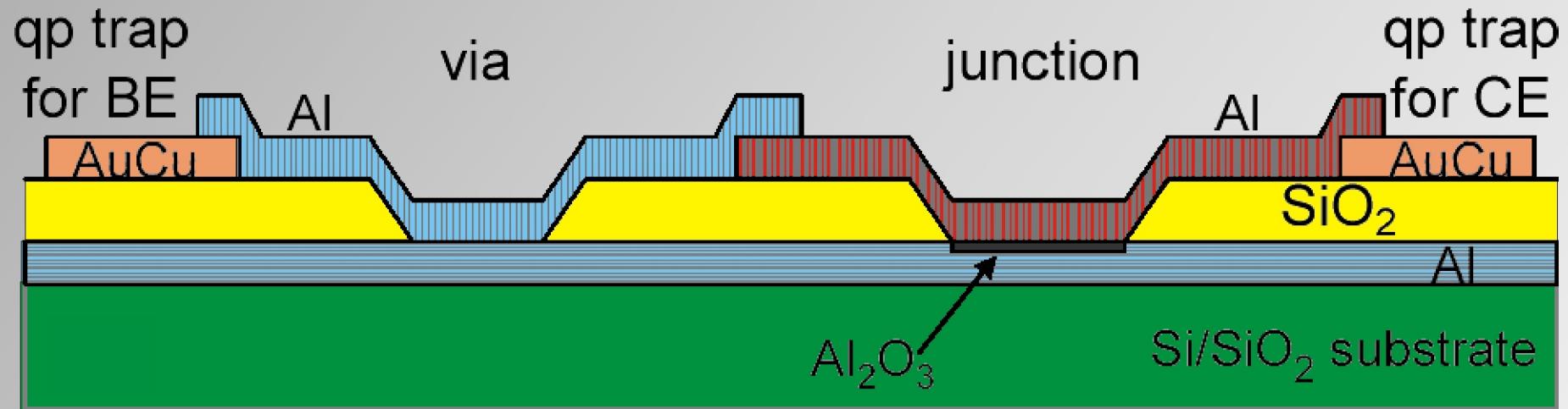
$$\tilde{H}_{int} = \frac{\Delta I_0}{2} \sqrt{\frac{\hbar}{2\omega_{10}C}} (|0\rangle \langle 1| \otimes |e\rangle \langle g| + |1\rangle \langle 0| \otimes |g\rangle \langle e|)$$

## Newest Improvements to the Qubit

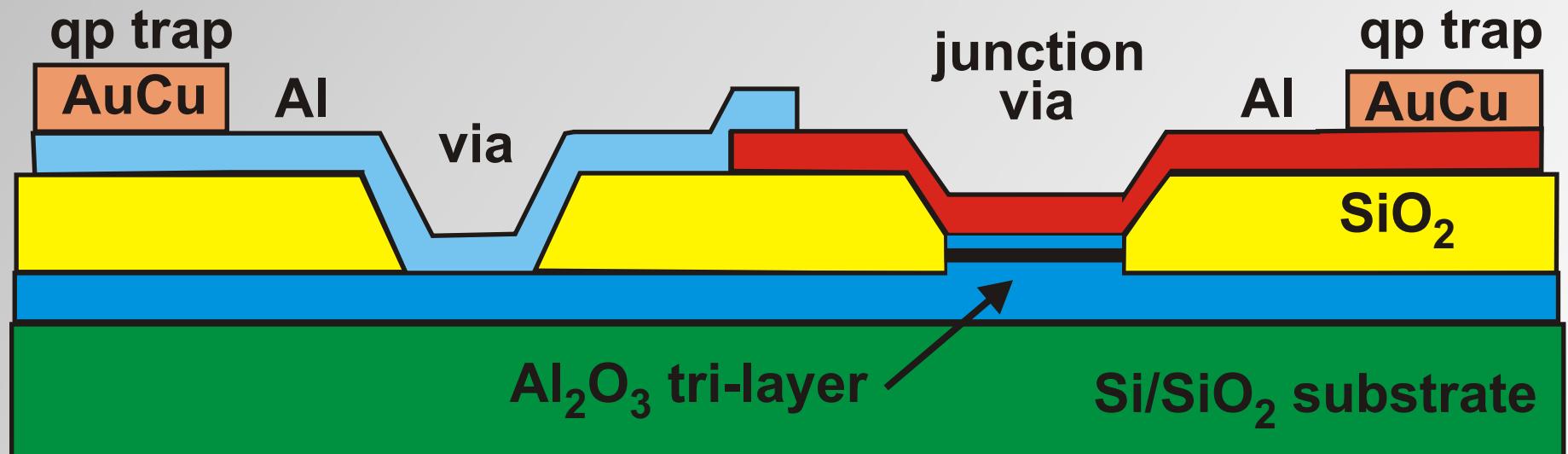
- Use gradiometer coils
- Move bias coil farther away.
- Fabricate a tri-layer junction.



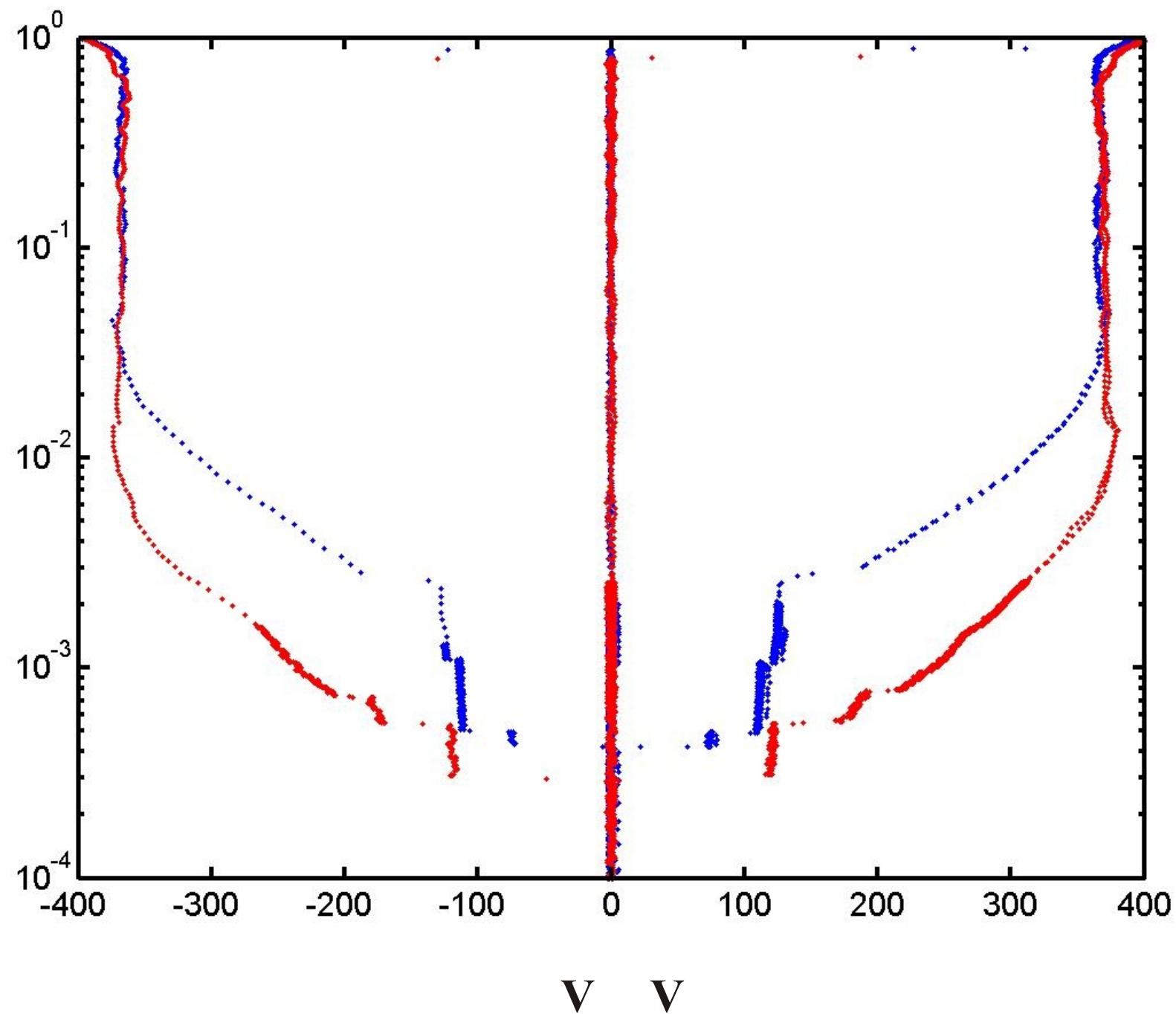
## Old Fab



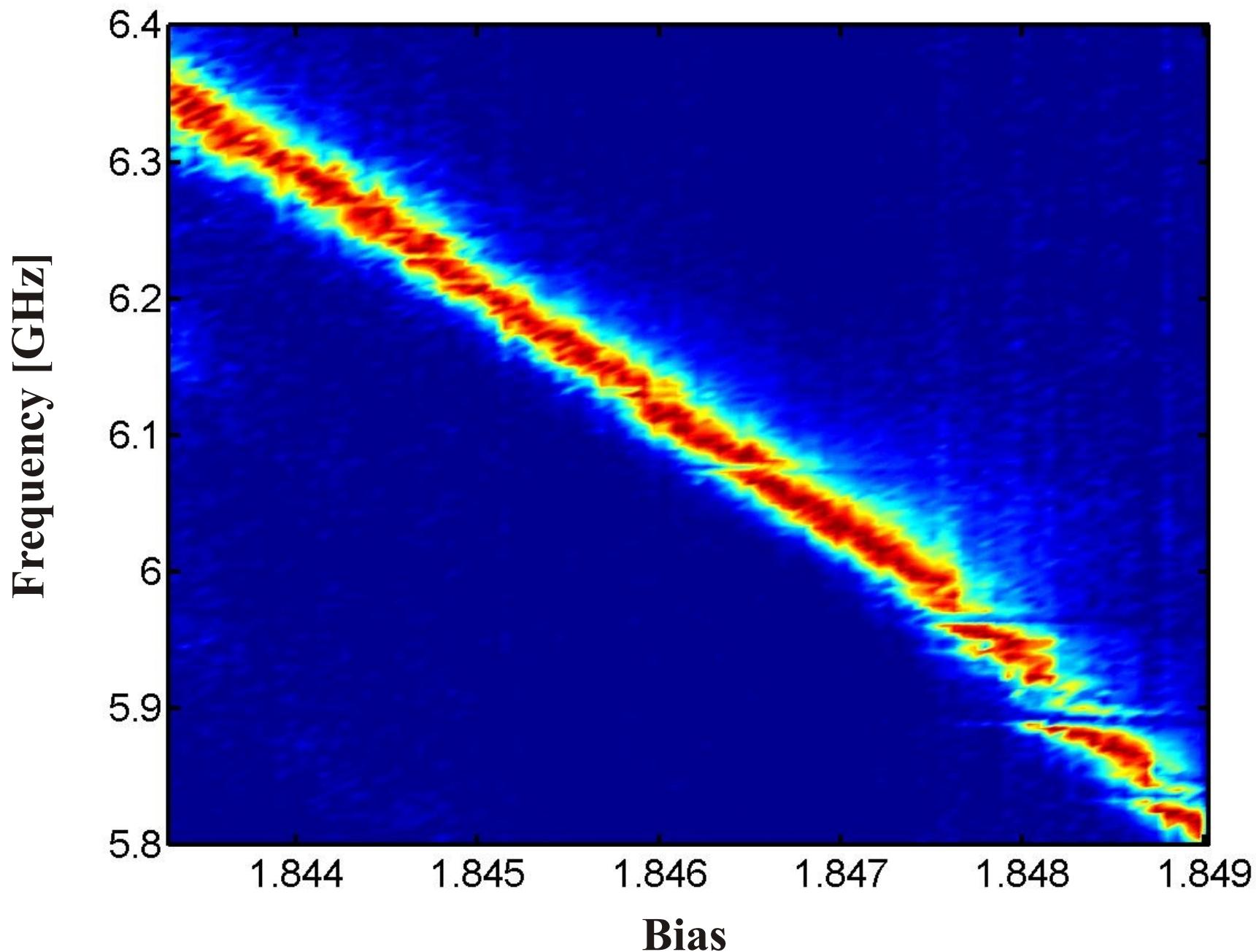
## New Fab



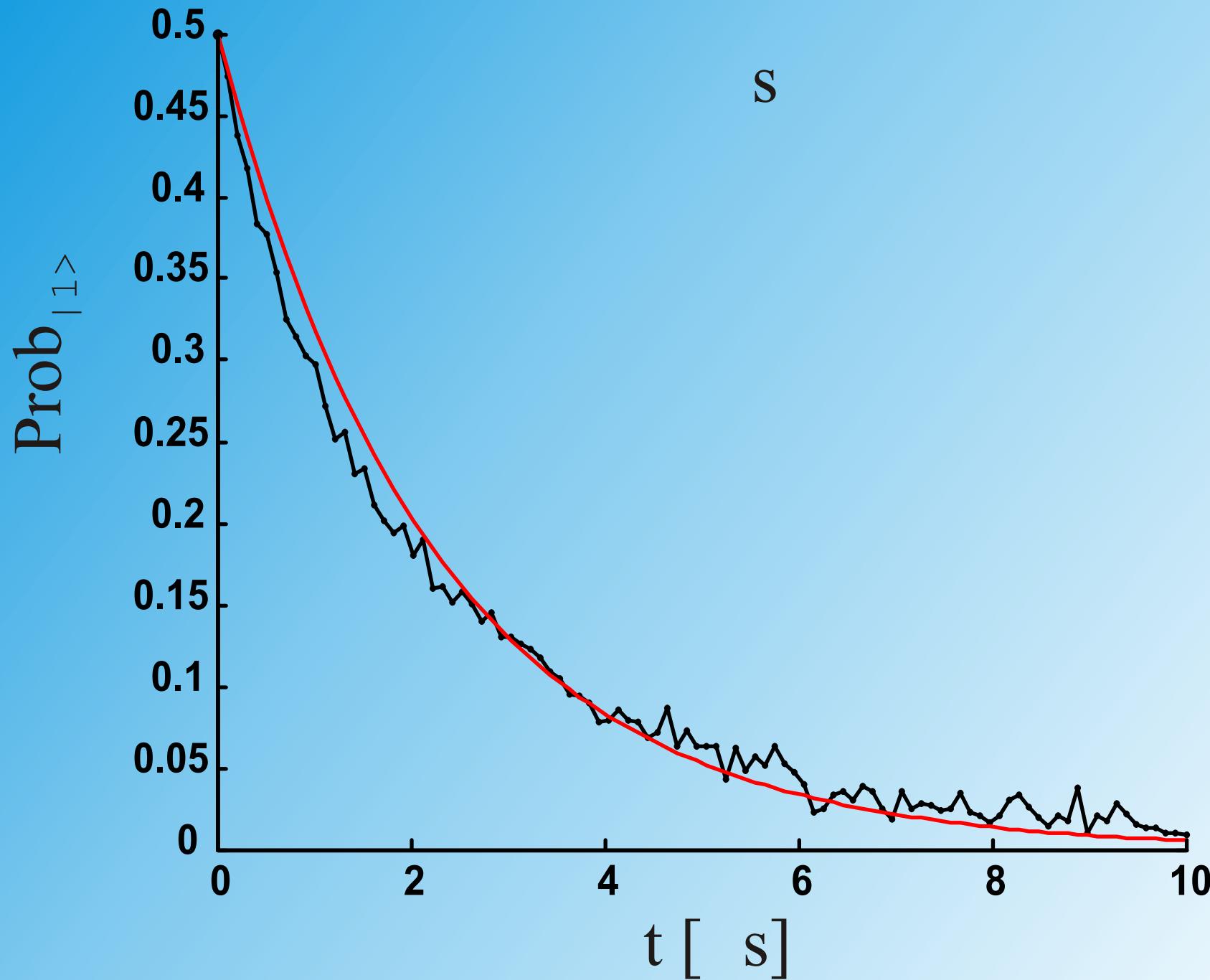
# Better I-Vs



## **Smaller Splittings**



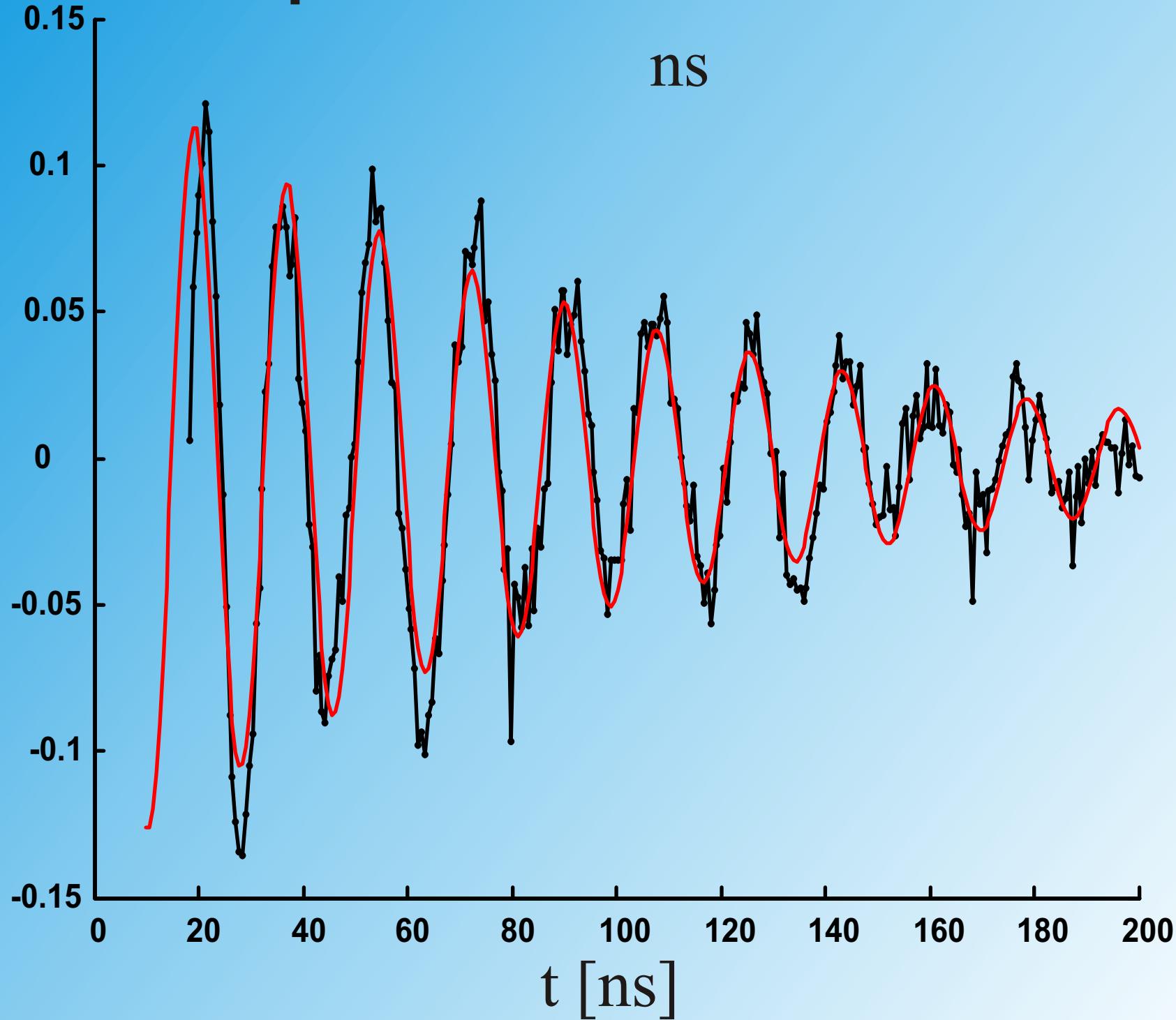
# Improved Energy Relation Time



# Improved Rabi Oscillations

ns

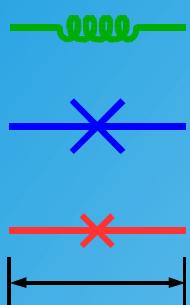
Prob  $|1\rangle - 0.5$



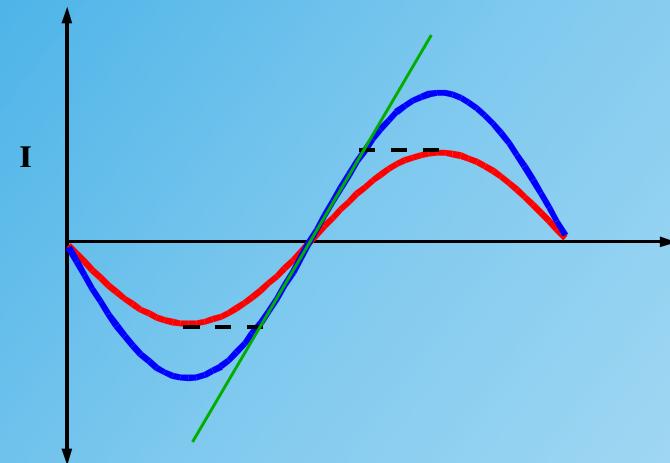
**WHAT IS IN YOUR HAMILTONIAN?**

# The Asymmetric d.c. SQUID

The Inductors

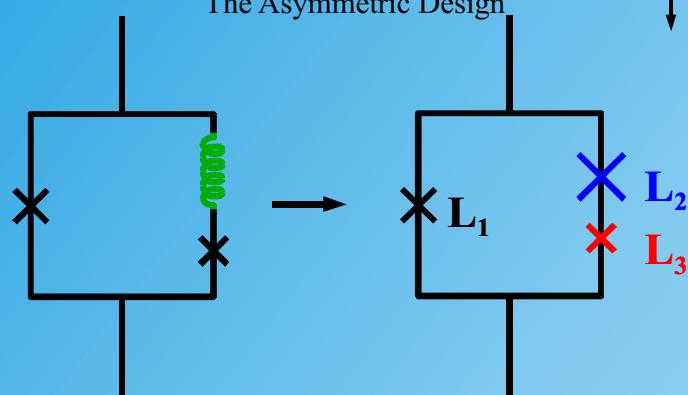


Current-Phase Relations

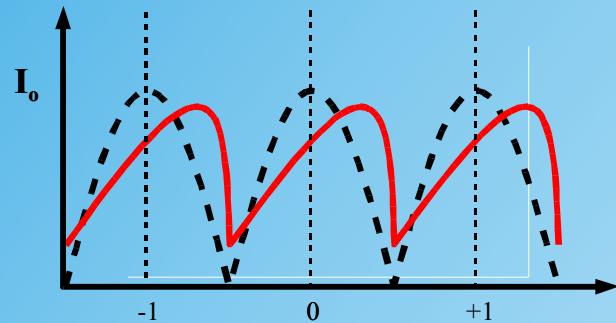


$$L_J(\phi) = \frac{1}{2} \frac{1}{I_o \cos(\phi)}$$

The Asymmetric Design

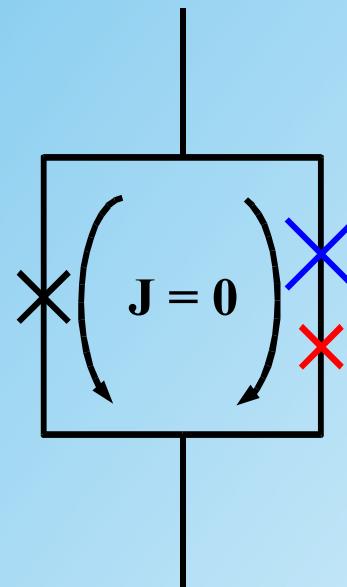


Modulation of the Critical Current



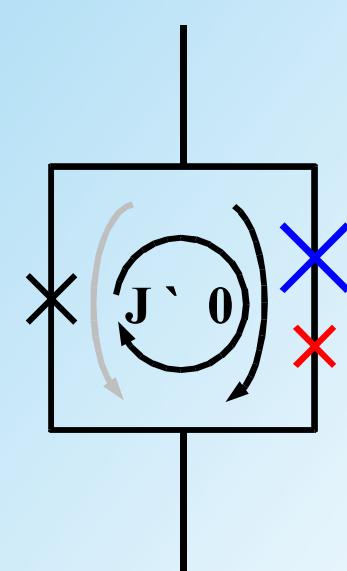
$I \sim 0$ : Symmetric Currents

$$L_1 = L_2 + L_3$$



$I \neq 0$ : Asymmetric Currents

$$L_1 \neq L_2 + L_3$$



# The Asymmetric d.c. SQUID

